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Evaluation of White Hake (*Urophycis tenuis*) populations in the NL Region in support of a Recovery Potential Assessment

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

In November 2013, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated White Hake (*Urophycis tenuis*, Mitchill 1815) in the Atlantic and Northern Gulf of St. Lawrence population as threatened. The Atlantic and Northern Gulf of St. Lawrence population includes White Hake in Newfoundland and Labrador waters and, in particular, those in Northwest Atlantic Fisheries Organization (NAFO) Divisions 3NO and Subdivision 3Ps.

In support of listing recommendations for White Hake by the federal Minister of Fisheries and Oceans (DFO), DFO-Science is conducting a Recovery Potential Assessment (RPA).

This document summarizes current knowledge of the biology, abundance, distribution, and life history of White Hake in Newfoundland and Labrador waters. In addition, habitat and residence requirements have been assessed through analyses of the relationship between research survey catches and water depth/bottom temperature. These analyses support the results of previous studies, which indicate a particularly robust association with warmer waters in excess of 4°C. The document also reviews available information on threats and factors which may limit the survival and recovery of White Hake. Through implementation of a Bayesian Surplus Production Model, potential recovery targets (based on the DFO Precautionary Approach Framework) are proposed. Furthermore, the scope for allowable harm and several scenarios for mitigation of threats and alternatives to anthropogenic activities are considered. There appears to be some scope for human-induced mortality without jeopardizing survival or recovery of this species in this stock area.

Évaluation des populations de merluche blanche (*Urophycis tenuis*) dans la région de Terre-Neuve-et-Labrador à l'appui d'une évaluation du potentiel de rétablissement

RÉSUMÉ

En novembre 2013, le Comité sur la situation des espèces en péril au Canada a désigné la population de merluche blanche (*Urophycis tenuis*; Mitchill 1815) de l'Atlantique et du nord du golfe du Saint-Laurent comme étant menacée. La population de l'Atlantique et du nord du golfe du Saint-Laurent comprend la merluche blanche située dans les eaux de Terre-Neuve-et-Labrador, plus particulièrement dans la division 3NO et la sous-division 3Ps de l'Organisation des pêches de l'Atlantique Nord-Ouest.

Pour appuyer les recommandations d'inscription de la merluche blanche par le ministre de Pêches et Océans Canada (MPO), le Secteur des sciences mène une évaluation du potentiel de rétablissement.

Le présent document résume les connaissances actuelles sur la biologie, l'abondance, la répartition et le cycle biologique de la merluche blanche dans les eaux de Terre-Neuve-et-Labrador. En outre, on a évalué les besoins en matière d'habitat et de résidence au moyen d'analyses de la relation entre les prises des relevés de recherche et la profondeur de l'eau/température au fond. Ces analyses soutiennent les résultats d'études antérieures, qui révèlent une association particulièrement solide avec les eaux plus chaudes dépassant 4 °C. Le document examine aussi les renseignements disponibles sur les menaces et les facteurs qui peuvent limiter la survie et le rétablissement de la merluche blanche. On a proposé des objectifs de rétablissement potentiels (fondés sur le cadre de l'approche de précaution du MPO) par suite de la mise en œuvre d'un modèle bayésien de production excédentaire. Par ailleurs, l'ampleur des dommages admissibles ainsi que plusieurs scénarios de mesures d'atténuation des menaces et solutions de rechange aux activités anthropiques sont pris en compte. La mortalité causée par l'homme pourrait être acceptée dans une certaine mesure sans compromettre la survie ou le rétablissement de l'espèce dans cette zone de stock.

INTRODUCTION

In November 2013, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the status of White Hake in Canadian waters, and proposed two Designatable Units (DUs) for this species: 1) Southern Gulf of St. Lawrence population (NAFO Div. 4T, and the northern part of Div. 4Vn); and 2) Atlantic and Northern Gulf of St. Lawrence population (NAFO Div. 4VWX, Div. 4RS, and Div. 3NOP). The former DU was designated as Endangered, while the latter DU was designated as Threatened. In support of listing recommendations for White Hake by the federal Minister of Fisheries and Oceans (DFO), DFO-Science was requested to conduct a Recovery Potential Assessment (RPA), based on Canada's RPA Guidance. Advice from an RPA may be used to inform both scientific and socio-economic considerations of a listing decision, development of a recovery strategy and action plan, decision-making regarding issuance of permits or agreements, formulation of exemptions and related conditions, and preparation of reporting requirements; all as per relevant sections of Canada's *Species at Risk Act* (SARA). The primary purpose of this paper is to update information on White Hake in Newfoundland and Labrador (NL) waters (a component of DU2) of the Northwest Atlantic Ocean, and inform the RPA of White Hake in Canada, scheduled for January 2015. Information is provided on its current status with respect to abundance, biomass, habitat associations, threats to its survival and recovery, and potential recovery targets.

BIOLOGY AND LIFE HISTORY

White Hake is a gadoid fish of the Family Phycidae. It is distributed mostly along the continental slope from Cape Hatteras to the southern Grand Bank, and in the waters of the Laurentian and Hermitage Channels, but also occurs in the Gulf of St. Lawrence, on the Scotian Shelf, and throughout the Bay of Fundy (Scott and Scott 1988; Kulka et al. 2005*a*; Simpson et al. 2012). White Hake has been reported as far north as the waters of Iceland and Greenland (Scott and Scott 1988; Cohen et al. 1990; Collette and Klein-MacPhee 2002). Musick (1974) described its southern limit as being the deep waters off of Florida.

The biology of White Hake in Newfoundland waters (Div. 3NO and Subdiv. 3Ps) was summarized in previous assessments (e.g., Kulka et al. 2005; Kulka and Miri 2007; Simpson et al. 2012).

Spawning in Newfoundland waters is proposed to occur during spring (Kulka et al. 2005*a*) or summer (Petrov 1973; Cohen et al. 1990). White Hake can potentially produce millions of eggs per spawner (Beacham and Nepszy 1980). Their eggs are buoyant, and remain in the upper water layer where they are dispersed by ocean currents (Han and Kulka 2007). Pelagic larvae hatch at 2-4 mm Total Length (TL), and have an extended juvenile stage (Markle et al. 1982; Fahay and Able 1989). These early life stages remain in the upper water layer for two to three months (depending on water temperature) prior to settlement (Markle et al. 1982; Lang et al. 1996).

Estuaries and eelgrass habitat can serve as nursery areas for demersal White Hake juveniles (Horne and Campana 1989; Gregory et al. 1997; Collette and Klein-MacPhee 2002; Laurel et al. 2003; Lazzari and Stone 2006; Ings et al. 2008). There is evidence of age-based segregation in White Hake populations: in one study, Young-of-the-Year (YOY) were found in shallow water (2-18 m) while older, larger juveniles were found in deeper water (28-73 m; Markle et al. 1982). Adults tend to occupy water deeper than that of juveniles; although both juveniles and adults move inshore in summer, and disperse to deeper water in winter (Sosebee 1998).

Maximum age of White Hake was reported to be 14-16 years by Petrov (1973), and 23 years by Beverton and Holt (1959).

ABUNDANCE AND DISTRIBUTION

Most data for White Hake in NL waters were obtained from Canadian bottom trawl research surveys conducted by DFO-NL during spring in NAFO Div. 3LNOP (1971-2014), and fall in Div. 2J3KLNO (1977-2013), which included waters beyond Canada's Exclusive Economic Zone (EEZ; Fig. 1). Details of these surveys, including changes in gear type and spatial coverage over time, are discussed in Doubleday (1981), Bishop (1994), McCallum and Walsh (1996), Walsh and McCallum (1996), Brodie and Stansbury (2007), Healey and Brodie (2009), and Simpson and Miri (2013a). In 1995, Spain initiated a survey in the NAFO Regulatory Area (NRA) of Div. 3NO. Details of this EU-Spain spring survey are provided in Simpson and Miri (2013a).

Using DFO-NL survey data, abundance and biomass were estimated by areal expansion of stratified arithmetic mean catch per tow (STRAP; Smith and Somerton 1981). The abundance index was expressed as mean fish number per standard tow, and the biomass index as mean weight (kg) per standard tow; both are reported for spring (Div. 3NO, Subdiv. 3Ps) and fall (Div. 3NO) surveys, which are not directly comparable.

The spring survey covers the entire stock area, and thus serves as the primary source of information on White Hake in NL waters. Spring abundance and biomass indices from 1972-2014 are presented for Div. 3NO and Subdiv. 3Ps combined (Fig. 2), as well as for Div. 3NO (Fig. 3) and Subdiv. 3Ps (Fig. 4) separately. However, Div. 3LNO were not surveyed in 1983, and the deeper (>103 m) portion of Div. 3NO, as well as Subdiv. 3Ps, were not surveyed in 2006 due to mechanical difficulties on Canadian research vessels. Indices for Subdiv. 3Pn are presented in Figure 5; although this Subdivision was not surveyed in 2006 and 2014. Since the last notable increases and subsequent declines in mean number and mean weight per tow (due to recruitment of a very large 1999 year-class), indices for Div. 3NO and Subdiv. 3Ps have varied without trend, but remained low. Indices in Subdiv. 3Pn have varied without trend since the introduction of the Campelen trawl in 1996.

Fall abundance and biomass indices for Div. 3NO are available for 1990-2013 (Fig. 6). Similar to the spring survey, fall biomass and abundance indices have varied without trend after recruitment of a very large year-class in 1999. Estimated percent change in abundance indices for White Hake from spring and fall surveys in Div. 3NOP over various time periods are presented in Table 1. Since 2004, spring and fall abundance indices in Div. 3NO have increased. In Subdiv. 3Ps, the spring abundance index decreased since the introduction of the Campelen trawl in 1996, but increased in Subdiv. 3Pn.

Recent biomass indices from the EU-Spain spring survey in the NAFO Regulatory Area (NRA) of Div. 3NO (González-Troncoso and Paz 2014) are provided in Figure 7. The EU-Spain biomass index has increased considerably since 2008, and the overall trend is similar to that of the Canadian spring biomass index for the entire Div. 3NO area.

HABITAT AND RESIDENCE REQUIREMENTS

During DFO-NL surveys, depth and bottom temperature were recorded at each tow location using trawl-mounted sensors (SIMRAD depth sounder, Seabird 19 CTD). Geo-referenced catch and hydrographic data for Canadian spring bottom trawl surveys were used to assess spatial distribution and habitat associations of White Hake throughout the study area.

Maps of the geographic distribution of White Hake catches were plotted using Canadian survey data from NAFO Subareas 2-5 (including data from spring and fall surveys in NL waters) in 1977-1990 (Fig. 8) and 2000-2013 (Fig. 9). Recent distributions of White Hake catches in Div. 3NO and Subdiv. 3Ps were consistent with historic survey catch data. Geographic distribution of catches indicated that White Hake in NL waters were found mostly along the continental shelf slope of the southwestern Grand Bank (Div. 3O), and in the Laurentian and Hermitage Channels (Div. 3P).

Using Campelen spring survey data (1996-2014), the association of White Hake density with the habitat variables of depth and bottom temperature in Div. 3O and Subdiv. 3Ps was studied using cumulative distribution functions (Perry and Smith 1994; Smith 1998). Analyses for Div. 3N were not conducted due to sporadic catches of White Hake in this Division. This method involved first constructing a design-weighted cumulative distribution function (cdf) of an observed habitat variable (i.e., depth or temperature) for a given year, as well as a catch and design-weighted cdf (based on proportions of the stratified mean associated with each point of the design-weighted cdf). A randomization test (based on the Kolmogorov-Smirnov test) used a chosen number of replications (1000) to create a null hypothesis distribution, and evaluated significance of the difference between both curves (i.e., maximum vertical distance between them).

Test results for statistical differences are presented for Div. 3O (Table 2) and Subdiv. 3Ps (Table 3). Cumulative frequency distributions of White Hake in Div. 3O reflected strong associations with bottom temperature (Fig. 10) and, to a lesser extent, depth (Fig. 11). CFDs in Subdiv. 3Ps indicated strong associations with both bottom temperature (Fig. 12) and depth (Fig. 13). Results are consistent with previous studies in NL waters, which indicated that White Hake are temperature-keepers, preferring warmer waters in excess of 4°C (Kulka and Mowbray 1998; Kulka et al. 2005; Simpson et al. 2012). Preferred depths depend on location, and may be influenced by temperature, as well as differences in surveyed depths between Div. 3O and Subdiv. 3Ps; the majority of tows in Div. 3O occurred in <200-m depths.

There is no evidence to suggest that the availability of suitable habitat is limiting recovery of White Hake, or that it will constrain this species once proposed recovery targets are reached (Colbourne et al. 2014).

THREATS AND LIMITING FACTORS TO SURVIVAL AND RECOVERY

FISHING MORTALITY

Commercial fisheries removals of White Hake in NAFO Subareas 0, 1, 2, and 3 were examined for 1960-2013, using commercial data in three databases: the Northwest Atlantic Fisheries Organization (NAFO) STATLANT-21A landings (1960-2013), as reported by NAFO-member countries; DFO- ZIFF (Zonal Interchange File Format) landings (1985-2013), as reported by Canadian fishers (recorded in their logbooks and on fish plants' purchase slips); and Canadian At-Sea Fisheries Observers' (ASO) catch and discard data (1979-2012), collected on a set-by-set basis in a standardized format on board commercial fishing vessels at sea. It must be noted that Canadian ASOs constitute the only reliable source of data on total catch by species, and discarding at sea.

Landings of White Hake occur mainly in NAFO Div. 3NOP, although they are occasionally reported in NAFO Div. 2J3KL (Fig. 14). The majority of landings from Div. 3P come from Subdiv. 3Ps. White Hake in the NRA of Div. 3NO is managed by the NAFO Fisheries Commission, which sets an annual Total Allowable Catch (TAC) for the stock. This TAC has been reduced considerably since its introduction in 2005. The stock is fished primarily by

Canada, EU-Spain, EU-Portugal, and Russia. In 1995, Canada commenced a directed fishery for White Hake in Div. 3NO of the Canadian EEZ. In Div. 3P, White Hake is fished almost exclusively by Canada, and is managed by DFO with input controls, as opposed to a TAC.

NAFO-reported landings (all member countries combined) in Div. 3NO peaked in 1987 at approximately 8,100 tonnes (t). Reported landings remained above 2,000 t until 1992, when a further decrease to roughly 1,700 t coincided with the restriction of fishing by other countries to areas outside Canada's 200-mile limit. Consequently, foreign reported landings fell to zero in the Canadian EEZ. Reported landings remained relatively low until the early 2000s. Following recruitment of a very large 1999 year-class of White Hake, NAFO-reported landings in the NRA of Div. 3NO increased to approximately 5,400 t in 2002 and 6,200 t in 2003, but then decreased sharply. Reported landings in Div. 3NO have not exceeded 500 t since 2009 (Table 4).

NAFO-reported landings of White Hake in Subdiv. 3Ps were generally lower than in Div. 3NO, and were largely attributed to fishing by Canadian fleets (Table 4; Fig. 14). However, most of the reported landings during the mid-1980s to the early 1990s should be interpreted with caution, as landings of Atlantic Cod by Canadian longline fisheries during this period were misreported as White Hake. Reported landings in Subdiv. 3Ps have not exceeded 500 t since 2009.

DFF-reported annual landings of White Hake from Div. 3NO*P* have varied considerably since 1985 (Fig. 15). Reported landings have changed little since 2011, and remained below 200 t, constituting the lowest values of the entire time series. *DFF*-reported landings represent landed bycatch of White Hake, as well as landings from the directed fishery for this species, all of which remained below 250 t annually since 2011 (Fig. 16).

White Hake in Div. 3NO*P* are caught in fisheries using gillnets, longlines, and otter trawls, with combined annual landings below 250 t since 2011 (Fig. 17). Bycatch of White Hake occurs mainly in fisheries for Atlantic Cod (*Gadus morhua*), Atlantic Halibut (*Hippoglossus hippoglossus*), Monkfish (*Lophius americanus*), and redfish (*Sebastes* spp.).

To estimate annual total catch of White Hake (i.e., landings + discards at sea) in gillnet and longline fisheries directing for this species in Canada's EEZ of Div. 3NO*P*, a method based on Campana et al. (2011) was used with the NL-ASO database for 1985-2012 (see Simpson and Miri 2013a for detailed methodology). However, catch estimates were dependent on the percentage of actual ASO coverage of each fishery in each year, as well as whether the DFO-NL *DFF* database contained reported landings of this species for each year of ASO coverage. Combined estimates for both gears peaked at 1,700 t in 2008, although most catches were observed in the White Hake-directed gillnet fishery during this period (Fig. 18). Annual catch estimates remained below 400 t since 2010.

Annual estimates of White Hake bycatch in Canada's EEZ of Div. 3NO*P* were averaged over 1985-2012 (Table 5). In 1997-2008, several fisheries targeting other groundfish also caught White Hake: the Atlantic Cod longline fishery averaged 219 t annually, the redfish gillnet fishery 216 t, the Atlantic Cod gillnet fishery 146 t, the Atlantic Halibut longline fishery 68 t, and the Monkfish gillnet fishery 32 t. Combined bycatch estimates peaked in 2008. Furthermore, combined annual bycatch estimates for White Hake in 2009-2012 have not exceeded 500 t, and were primarily from the longline fishery directing for Atlantic Cod (250 t average annually), while the Atlantic Halibut longline and Atlantic Cod gillnet fisheries annually averaged 42 t and 29 t, respectively.

The decline in White Hake biomass following a large recruitment event in 1999-2000 has been attributed to fishing (Rutka and Miri 2007). There are no data available concerning the impact of fishing gears on White Hake habitat.

RECRUITMENT AND NATURAL MORTALITY

An index of recruitment at age 1 was derived from DFO (in prep.), spring survey catches of White Hake aged 1 yr in Div. 3NOPs (Fig. 19). Except for a very large recruitment index in 2005, the recruitment index was generally very low in all years, with small peaks in 1998 and 2011.

Han and Kulka (2009) investigated dispersion and survival potential of White Hake eggs, larvae and juveniles with a three-dimensional regional ocean circulation model. Their results suggested that a weak along-shore current and strong on-bank flow increase juvenile retention on the southern Grand Banks. In addition, spawning below the surface (longer eggs in late spring) maximizes chances for White Hake juveniles to settle on the southern Grand Banks in autumn.

Causes of natural mortality for White Hake in 4X, waters are not well understood. In the Gulf of St. Lawrence, White Hake can constitute a large part of the diet of both Grey Seals (*Halichoerus grypus*) and Harp Seals (*Phoca groenlandica*). Hammill and Stenson (2000, Hammill et al. 2014), Benoît et al. (2011) suggested that predation by Grey Seals on White Hake in the southern Gulf of St. Lawrence has elevated adult natural mortality to the extent that it is responsible for a decline in White Hake abundance. Hammill et al. (2007) did not find any White Hake in Grey Seal stomachs collected along Newfoundland's south coast in 1999-2006, although the sample size was very small (n=24). Predation by seals in 4X, waters may contribute to the levels of White Hake abundance, but further studies with larger sample sizes are necessary to quantify any effects of seal predation on White Hake abundance in Div. 3NO and Subdiv. 3Ps.

SEISMIC EXPOSURE

Seismic surveys are widely used to detect potential drilling locations for oil and gas reserves, and involve sending sound waves down to the sea floor and recording echoes that return from various sedimentary layers.

Impacts on White Hake and their physical habitat are unlikely to occur, but there could be effects on various life stages of their prey.

OIL AND GAS

Currently, there are no oil and gas drilling activities in the area associated with the 4X, portion of the Div. However, there are significant drilling license (SDL) areas immediately north of Div. 3NO: Hibernia, Terra Nova, White Rose, and North Amethyst oil fields are currently in operation in the Jeanne d'Arc Basin. The Hebron oil field will become operational in 2017. Any significant oil pollution north of Div. 3NO could be transported by the Labrador Current into the area, and thus potentially impact White Hake (especially eggs and larvae) and their habitat.

There are no data currently available on the impact of oil and gas drilling, or of oil pollution, on White Hake or its habitat.

CLIMATE CHANGE

White Hake are temperature-keepers, and appear to prefer warmer waters in excess of 6°C (Kulka and Woodley 1998, Kulka et al. 2005, Simpson et al. 2012). Warming of ocean temperatures may have significant impacts on White Hake in Div. 3NO and Subdiv. 3Ps, although it is currently not possible to quantify these effects.

[redacted]

[redacted]

Population dynamics of White Sea dominant species were modelled with a Bayesian state-space implementation of the Schaefer Surplus Production (SP; Schaefer 1954) model for stocks in the Arctic and Subarctic (IPA), using WFS-VL research survey data and WMFS reported landings from 1964–2015. SP models were chosen due to a lack of age-disaggregated data for this population, and follow [redacted] light-data-pilot which is developing length-based models. The general SP model formulation was previously described in Walsby (2014) for American Plaice (*Pleuronectes plecostomus*).

White Sea dominant was modelled historically using estimated prior for K (...) and r (Table 6). WMFS reported landings, population biomass estimates from WFS-VL research surveys and from the Spawn survey of 2015. IMO were incorporated into the model as observed data with error. Models were examined for convergence, and population parameters were inferred for 10,000 MCMC posterior samples using different realizations of fishing mortality and catch for the Arctic and Subarctic (IPA). These were:

1. No Fishing mortality, $F = 0$
2. Fishing mortality, $F_{current}$ = mean of F for past 10 years
3. Fishing mortality at Maximum Sustainable Yield (MSY), F_{MSY}
4. Trade Allowance Catch

Data

The following data were used from the IMSPA:

1. WMFS reported landings (ENVELOPE) (t/yr) — 1964–2015
2. Convention Research Survey Indices: Spring Harbour Series — 1972–1982
3. Convention Research Survey Indices: Spring Ocean Series — 1964–1995
4. Convention Research Survey Indices: Spring Composite Series — 1996–2015
5. Convention Research Survey Indices: Fall Ocean Series — 1965–1995
6. Convention Research Survey Indices: Fall Composite Series — 1996–2015
7. WJ Ryan Research Survey Indices: Spring Composite Series — 2001–2015

Detailed descriptions of the above data are available in Schubert et al. (2015a).

Prior Distributions

Non-informative priors were used for variability (σ), and for observation and process errors. These priors were given non-informative gamma distributions.

Vague priors were also used for carrying capacity (K), and the intrinsic rate of population increase (r; Table 6). Typically, r is set to above dominance in the year prior to onset of fishing (F_0; Meuck and Miller 1998). However, a models used here, since dominance in 1964 was not necessarily assumed to be virgin biomass. Therefore, F_0 was allowed to vary between 0.1 and 1.0 (i.e. initial biomass was allowed to vary between 0.1 K and K).

A lognormal distribution for K was specified here with a mean of 100,000t (across) and a standard deviation of 100,000t (+/- 1sd). IMO were Arctic, IPA. The distribution of K was set to

[illegible] [illegible] [illegible] [

[illegible]

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APPENDIX A

Table 1. Estimated percent change within periods for all sizes of White Hake abundance indices from the DFO-NL research surveys conducted in NAFO Div. 3NOP.

Management area	Survey	Size group	Time period	Instantaneous rate of change over period	Total change over period (years)
3NO	Spring RV - Engel	All sizes	1984 - 1995	-0.004	- 4.2 % (12)
3NO	Spring RCampelen	All sizes	1996 - 2014	0.00007	- 0.1 % (19)
3NO	Spring RCampelen	All sizes	2004 - 2014	0.02	23.4 % (11)
3NO	Fall RV - Engel	All sizes	1990 - 1994	-0.024	- 11.3 % (5)
3NO	Fall RV - Campelen	All sizes	1995 - 2013	-0.003	- 5.8 % (19)
3NO	Fall RV - Campelen	All sizes	2004 - 2013	0.086	135.8 % (10)
3Ps	Spring RV - Engel	All sizes	1984 - 1995	-0.005	- 5.9 % (12)
3Ps	Spring RCampelen	All sizes	1996 - 2014	-0.02	- 29.1 % (19)
3Pn	Spring RV Engel	All sizes	1986 - 1995	-0.06	- 45.8 % (10)
3Pn	Spring RCampelen	All sizes	1996 - 2013	0.03	+ 74.8 % (18)

Table 2. Test results for statistical differences in the White Hake catch and design-weighted cumulative frequency distributions compared with the design-weighted cumulative frequency distributions of bottom depth and temperature for Div. 3O, using data from the DFO-NL spring Campelen survey in 1996-2014. Table entries are probability (p) values for having a test statistic (from the randomization procedure) as great, or greater, than that which was observed.

Year	Depth	Temperature
1996	0.001	0.001
1997	0.001	0.001
1998	0.001	0.001
1999	0.001	0.001
2000	0.055	0.001
2001	0.001	0.001
2002	0.001	0.001
2003	0.001	0.001
2004	0.001	0.001
2005	0.03	0.001
2006	N/A	N/A
2007	0.001	0.001
2008	0.028	0.001
2009	0.001	0.001
2010	0.001	0.001
2011	0.218	0.001
2012	0.012	0.001
2013	0.001	0.001
2014	0.001	0.001

Table 3. Test results for statistical differences in the White Hake catch-weighted cumulative frequency distributions compared with the unweighted cumulative frequency distributions of bottom depth and temperature for Subdiv. 3Ps, using data from the DFO-NL spring survey in 1996-2014. Table entries are probability (p) values for having a test statistic (from the randomization procedure) as great, or greater, than that which was observed.

Year	Depth	Temperature
1996	0.001	0.001
1997	0.001	0.001
1998	0.001	0.001
1999	0.001	0.001
2000	0.001	0.001
2001	0.001	0.001
2002	0.001	0.001
2003	0.001	0.001
2004	0.001	0.001
2005	0.001	0.001
2006	N/A	N/A
2007	0.001	0.001
2008	0.001	0.001
2009	0.001	0.001
2010	0.001	0.001
2011	0.001	0.001
2012	0.001	0.001
2013	0.001	0.001
2014	0.001	0.001

Table 4. NAFO STATLANT-21A reported landings of White Hake (tonnes) in NAFO Div. 3NO and Subdiv. 3Ps/3Pn, 1960-2013.

Year	Div. 3N non-Can	Div. 3N Canada	Div. 3O non-Can	Div. 3O Canada	Subdiv. 3Ps non-Can	Subdiv. 3Ps Canada	Subdiv. 3Pn non-Can	Subdiv. 3Pn Canada	Div. 3P Total	3NO Total	3NOPs Total
1960	164	37	210	181	500	232	-	-	732	592	1324
1961	9	17	25	152	32	100	4	4	140	203	335
1962	1	2	1384	406	1	74	-	21	96	1793	1868
1963	-	12	5	129	8	103	-	4	115	146	257
1964	-	14	-	113	-	124	-	18	142	127	251
1965	125	5	18	28	60	71	-	22	153	176	307
1966	4	9	102	51	45	39	-	8	92	166	250
1967	549	24	967	34	43	67	72	133	315	1574	1684
1968	-	5	22	64	20	403	-	202	625	91	514
1969	9	1	7	49	6	375	-	153	534	66	447
1970	21	48	44	107	227	397	30	177	831	205	829
1971	366	132	4110	2584	221	1443	-	295	1959	7192	8856
1972	259	34	1594	1998	115	2062	-	203	2380	3885	6062
1973	33	59	307	2508	84	1330	-	169	1583	2907	4321
1974	214	31	358	2476	18	1305	-	59	1382	3079	4402
1975	1186	43	2430	1926	765	1432	-	109	2306	5583	7780
1976	663	237	1272	1225	10	1344	-	122	1476	3397	4751
1977	1005	22	976	1095	-	1683	-	176	1859	3098	4781
1978	670	42	1199	682	-	1051	-	235	1286	2593	3644
1979	246	44	919	360	-	660	-	144	804	1569	2229
1980	209	242	1856	311	-	546	-	130	676	2618	3164
1981	809	22	564	310	-	1030	-	123	1153	1705	2735
1982	687	5	913	336	-	773	-	83	856	1941	2714
1983	271	30	1912	683	-	425	-	122	547	2896	3321
1984	400	108	3182	645	-	683	-	63	746	4335	5018
1985	1542	110	2835	1672	-	1156	-	57	1213	6159	7315
1986	473	394	1569	2169	14	1228	-	92	1334	4605	5847
1987	4019	1321	990	1731	-	1318	-	66	1384	8061	9379
1988	866	830	111	954	12	683	-	22	717	2761	3456
1989	5	878	23	1103	3	706	-	4	713	2009	2718

Table 4. Cont'd.

Year	Div. 3N non-Can	Div. 3N Canada	Div. 3O non-Can	Div. 3O Canada	Subdiv. 3Ps non-Can	Subdiv. 3Ps Canada	Subdiv. 3Ps non-Can	Subdiv. 3Ps Canada	Div. 3P Total	3NO Total	3NOPs Total
1990	228	832	7	1053	35	1441	-	13	1489	2120	3596
1991	1507	20	-	950	36	1445	-	44	1525	2457	3968
1992	-	19	-	1647	-	1206	-	80	1286	1666	2814
1993	-	18	-	1004	-	741	-	244	985	1022	1763
1994	20	16	4	253	-	382	-	294	676	293	671
1995	5	-	1	276	-	420	-	59	479	282	702
1996	28	-	1	311	-	362	-	80	442	340	702
1997	92	-	6	329	-	315	-	9	324	427	742
1998	81	-	8	186	1	561	-	8	570	277	839
1999	51	43	13	322	-	575	-	34	609	429	1004
2000	124	21	29	393	134	976	-	60	1170	567	1677
2001	73	18	49	493	10	920	-	141	1071	633	1563
2002	1221	-	3132	1014	3	915	-	52	970	5367	6285
2003	2688	-	3053	417	3	1105	-	210	1318	6158	7266
2004	170	6	1364	375	22	1361	-	77	1460	1915	3298
2005	21	0	258	685	23	1615	-	45	1683	964	2602
2006	73	2	178	950	1	1464	-	15	1500	1203	2688
2007	12	10	74	627	2	1253	-	35	1290	723	1973
2008	26	6	60	778	6	659	-	45	710	870	1535
2009	19	3	70	389	-	382	-	26	408	481	843
2010	20	13	65	174	-	378	-	19	397	272	650
2011	3	-	94	66	-	200	-	41	241	163	383
2012	3	6	83	50	-	237	-	18	255	142	379
2013	10	-	112	83	-	167	-	24	191	305	372

Table 6. Estimated total catch (tonnes, average and 95% confidence intervals) of White Hake in various Div. 3NOP fisheries over 1985-2012. Data are from Canadian At-Sea Fisheries Observers and DFO-NL ZIFF in comparable years.

Gear Type	Directed species	Estimated catch (t) – Average	Estimated catch (t) – 95% Confidence intervals
Gillnets	White Hake	363.7	245.1 – 543.2
Gillnets	Atlantic Cod	138.4	97.4 – 196.4
Gillnets	Monkfish	46.2	11.1 – 89.2
Gillnets	redfish	163.1	75.2 – 253.4
Longlines	White Hake	2633.8	1731.6 – 3333.8
Longlines	Atlantic Cod	1227.9	946.2 – 1648.8
Longlines	Atlantic Halibut	53.8	25.8 – 87.1
Other trawls	Atlantic Cod	6.4	3.4 – 9.3
Other trawls	redfish	97.5	16.2 – 180.8
Other trawls	Witch Flounder	16.8	8.8 – 25.3

Table 4: Prior for parameters used in the surplus production model for the [redacted] stock. Prior distribution codes for r (intrinsic rate of population growth), K (carrying capacity), and q (catchability) are given parameters with (r) K and MSY (r K) quantities and the distribution used.

Parameter	Description	Prior Distribution
K	Carrying Capacity	[redacted]
r	Population growth rate	[redacted]
q_ytrs	Catchability, Canadian Yankee Trawl Series	[redacted]
q_s.cant	Catchability, Canadian Spring Campelen Trawl Survey	[redacted]
q_f.cant	Catchability, Canadian Fall Campelen Trawl Survey	[redacted]
q_s.engl	Catchability, Canadian Spring Engel Trawl Survey	[redacted]
q_f.engl	Catchability, Canadian Fall Engel Trawl Survey	[redacted]
q_eu	Catchability, European Union Series	[redacted]
Sigma	Process error	[redacted]
tau_ytrs	Observation error, Canadian Yankee Trawl	[redacted]
tau_s.cant	Observation error, Canadian Spring Campelen Trawl	[redacted]
tau_f.cant	Observation error, Canadian Fall Campelen Trawl	[redacted]
tau_s.engl	Observation error, Canadian Spring Engel Trawl	[redacted]
tau_f.engl	Observation error, Canadian Fall Engel Trawl	[redacted]
tau_eu	Observation error, European Union Series	[redacted]

Table 7 (cont'd)

Run	Parameter(s) Adjusted	ρ	Φ	Sigma	η_t s.errg	η_t s.conv	Tau s.errg	Tau s.conv	DIC
11	y ~ mean=0, sd=0.1; ρ = dbeorm(0.1,100)I(0,1); Φ~dunif(0,5000); η_t all same~dnorm(1,5)I(0,); sigma ~ dunif(0,1); tau all same~dunif(0.5,0.5);	0.29 (0.13 – 0.36)	52.2 (38.1 – 3483.2)	0.18 (0.01 – 0.39)	0.58 (0.27 – 0.88)	1.19 (0.69 – 1.79)	0.68 (0.53 – 1.02)	0.63 (0.46 – 0.87)	313
12	As 11 but tau prior widened to all same~dunif(0.3,1, .2)	0.25 (0.16 – 0.33)	91.3 (38.7 – 4594.0)	0.37 (0.17 – 0.53)	0.39 (0.19 – 0.71)	1.06 (0.57 – 1.67)	0.22 (0.02 – 0.63)	0.20 (0.02 – 0.63)	-1552
13	Using Φ in calculation of process error. No change in priors.	0.25 (0.16 – 0.33)	91.3 (38.7 – 4594.0)	0.37 (0.17 – 0.53)	0.39 (0.19 – 0.71)	1.06 (0.57 – 1.67)	0.22 (0.02 – 0.63)	0.20 (0.02 – 0.63)	-1552
14	As 13 but Fall and Elu data removed	0.15 (0.02 – 0.31)	1,26 (e+1.2 – 113,03)	0.37 (0.21 – 0.52)	0.20 (0.03 – 0.39)	0.60 (0.18 – 1.27)	0.18 (0.02 – 0.33)	0.16 (0.02 – 0.37)	-1,233
15	As Run 5 but Φ normal Φ~dnorm(100,0.0004)I(0,500);	0.15 (0.02 – 0.30)	88.3 (e+2.2 – 1888.5)	0.18 (0.07 – 0.28)	0.20 (0.05 – 0.40)	0.58 (0.22 – 1.30)	0.01 (0.001, 0.25)	0.02 (0.001, 0.13)	1116
16	As 15 but Φ prior set to lognormal: mean 100, sd=50 so Φ~dlnorm(4.49,4.49)I(0,500);	0.16 (0.02 – 0.40)	777.8 (e+3.9 – 1931.8)	0.18 (0.07 – 0.28)	0.20 (0.05 – 0.40)	0.60 (0.23 – 1.34)	0.01 (0.001, 0.15)	0.02 (0.001, 0.11)	1162
17	Prior on η_t mean=0, tr2, sd=0.1; η_t = dnorm(2.08,2.1^2)I(0.001,0.8);	0.19 (0.05 – 0.37)	79.5 (e+3.5 – 1461.6)	0.18 (0.07 – 0.28)	0.0271 (0.005 – 0.40)	0.62 (0.23, 1.32)	0.01 (0.001, 0.13)	0.02 (0.001, 0.11)	1136
18	As 5 but with 3000000 iterations, burn-in of 1000000 and thinning at 20	0.17 (0.01 – 0.32)	87.8 (35.8 – 2115.3)	0.18 (0.07 – 0.28)	0.21 (0.05 – 0.41)	0.59 (0.23 – 1.35)	0.01 (0.001 – 0.14)	0.02 (0.001 – 0.11)	71
19	As 17 but using Φ in calculation of process error and Φ prior set to mean=100, sd=100 Φ~dlnorm(4.22,1.44)I(0,500);	0.19 (0.05 – 0.39)	93.1 (37.5 – 1448.8)	0.18 (0.07 – 0.28)	0.23 (0.05 – 0.46)	0.63 (0.26 – 1.32)	0.01 (0.001 – 0.14)	0.02 (0.001 – 0.11)	1146

Table 8. Summary of parameter posteriors and their priors for the White Hake surplus production model (Div. 3NOPs). Prior stochastic nodes for r (intrinsic rate of population growth), K (carrying capacity), and q (catchability) are presented with 2.5 % and 97.5 % quantiles and the distribution used.

Parameter	Description	Prior Distribution	Posterior
K	Carrying Capacity	lognormal (μ=100 kt, sd=100 kt); 2.5 % and 97.5 % quantiles at 13.83 kt and 361.54 kt	67.0 (33.0 – 215.5)
R	Population growth rate	lognormal (μ=0.1, sd=0.2); 2.5 % and 97.5 % quantiles at 0.004 and 0.54	0.17 (0.01 – 0.50)
q.ynke	Catchability, Canadian Yankee Trawl Series	Gamma (μ=1, sd=1); 2.5 % and 97.5 % quantiles at 0.13 and 3.62	0.12 (0.05 – 0.28)
q.eu	Catchability, European Union Series	Gamma (μ=1, sd=1); 2.5 % and 97.5 % quantiles at 0.13 and 3.62	0.04 (0.014 – 0.10)
q.s.eng	Catchability, Canadian Spring Engel Trawl Series	Gamma (μ=1, sd=1); 2.5 % and 97.5 % quantiles at 0.13 and 3.62	0.21 (0.08 – 0.47)
q.f.eng	Catchability, Canadian Fall Engel Trawl Series	Gamma (μ=1, sd=1); 2.5 % and 97.5 % quantiles at 0.13 and 3.62	0.07 (0.02 – 0.22)
q.s.cam	Catchability, Canadian Spring Campelen Trawl Series	Gamma (μ=1, sd=1); 2.5 % and 97.5 % quantiles at 0.13 and 3.62	0.59 (0.23 – 1.35)
q.f.cam	Catchability, Canadian Fall Campelen Trawl Series	Gamma (μ=1, sd=1); 2.5 % and 97.5 % quantiles at 0.13 and 3.62	0.31 (0.12 – 0.72)
Sigma	Process error	Gamma (0.01,0.01)	0.14 (0.07 – 0.26)
tau.ynke	Observation error, Canadian Yankee Trawl	Gamma (0.01,0.01)	0.02 (0.001 – 0.29)
tau.eu	Observation error, European Union Series	Gamma (0.01,0.01)	0.61 (0.29 – 1.65)
tau.s.eng	Observation error, Canadian Spring Engel Trawl	Gamma (0.01,0.01)	0.01 (0.001 – 0.14)
tau.f.eng	Observation error, Canadian Fall Engel Trawl	Gamma (0.01,0.01)	0.36 (0.10 – 2.81)
tau.s.cam	Observation error, Canadian Spring Campelen Trawl	Gamma (0.01,0.01)	0.02 (0.001 – 0.11)
tau.f.cam	Observation error, Canadian Fall Campelen Trawl	Gamma (0.01,0.01)	0.22 (0.10 – 0.48)
MSY	Maximum Sustainable Yield	-	3.09 (0.24 – 8.26)
F_{MSY}	F at MSY	-	0.087 (0.007 – 0.25)
B_{MSY}	Biomass at MSY	-	33.5 (16.5 – 107.7)
DIC	Deviance Information Criteria	-	71

Table 9. Stock status indicators for White Hake in NAFO Div. 3NOPs after 5, 10, 15 and 27 years. Fishing mortality is based on constant F (F=0.00, $F_{current}$=0.03, F=F_{MSY}=0.087, and TAC=2000 t). B_{FINAL} is the biomass in the final year of the projection (i.e. 2018 for 5-year horizon). Probabilities (P) are presented for 2 stock status indicators: B_{FINAL} will be above: (1) the Limit Reference Point (40 % of B_{MSY}) in the final year of the time period, and the Upper Stock Reference (80 % of B_{MSY}) in the final year of the time period.

Fishing Mortality-	Projection	P (B_{FINAL} >0.4* B_{MSY}) LRP=13kt	P (B_{FINAL} >0.8* B_{MSY}) USR=26.3kt
F=0.0	5 years	0.85	0.62
-	10 years	0.88	0.72
-	15 years	0.90	0.76
-	27 years	0.92	0.79
-	-	-	-
F=$F_{current}$=0.03	5 years	0.83	0.58
-	10 years	0.86	0.66
-	15 years	0.87	0.70
-	27 years	0.88	0.71
-	-	-	-
F_{MSY}=0.087	5 years	0.77	0.46
-	10 years	0.74	0.46
-	15 years	0.73	0.46
-	27 years	0.71	0.46
-	-	-	-
F=TAC=2kt	5 years	0.89	0.66
-	10 years	0.93	0.73
-	15 years	0.94	0.76
-	27 years	0.85	0.68

Table 10a. Details of the White Hake fishery in NL waters.

Type of fishery (commercial, recreational)	Mitigation Measures- Fishing method (longlines, gillnets, trawl, hook & line)	Mitigation Measures- Fishing gear characteristics (mesh/pot/hook number and sizes)	Mitigation Measures- Number of active licenses/ number of licenses eligible	Mitigation Measures- Fishing season dates
Commercial <65' fleet	Longlines	Maximum of 4000 hooks, minimum hook size is 12.6 mm.	19/792	July 15-Sept. 30
Commercial <65' fleet	Longlines; Gillnets	In Subdiv. 3Ps, longlines with a maximum of 6,000 hooks and/or 100 gillnets. In 3Ps, longlines with a maximum of 4,000 hooks, and/or 20 gillnets. Minimum mesh size for gillnets is 152 mm (6 inches), maximum mesh size is 215 mm (8 ½ inches).	172/1800	Mid-May to March 31
Commercial <65' fleet	Gillnets	Maximum of 100 gillnets. Minimum mesh size is 152 mm (6 inches), maximum mesh size is 178 mm (7 inches).	15/2800	April 1-March 31
Commercial Fixed Gear 65'-100' vessels	Hook and line; Gillnets	Minimum hook size is 15.4 mm; no gear limit. Maximum of 500 gillnets, minimum mesh size is 165 mm (6.5 inches).	<5/10	April 1-March 31

Table 10b. Details of the White Hake fishery in NL waters.

Type of fishery (commercial, recreational)	Mitigation Measures- Fishing locations (NAFO Div., Subdiv.)	Mitigation Measures- Minimum fish size limits	Mitigation Measures- Fishery data (total reported landings)	Mitigation Measures- Quota
Commercial <65' fleet	3Pn	45 cm	10.8 mt	No quota
Commercial <65' fleet	3Ps	NA	253 mt by all fleets	No quota
Commercial <65' fleet	3NO	NA	110 mt directed, 10 mt bycatch	294 mt
Commercial Fixed Gear 65'-100' vessels	3NOPs	NA	253 mt by all fleets	294 mt in 3NO, no quota in 3Ps

Table 10c. Details of the White Hake fishery in NL waters.

Type of fishery (commercial; recreational)	Other control measures	Other control measures	Bycatch - other species in White Hake fishery (% of total kept weight of authorized White Hake aboard vessel)	Bycatch - Mitigation measures for bycatch in White Hake fishery	Bycatch - White Hake in other NL fisheries
Commercial <65' fleet	Water depths >125 fathoms	Dockside Monitoring Program (DMP), At-Sea Observer (ASO) coverage, Vessel Monitoring System (VMS)	Atlantic Halibut limit 10% to maximum of 200 lbs	Depth restriction, bycatch limits	Atlantic Cod gillnet, longline
Commercial <65' fleet	Water depths >75 fathoms. No fishing in Unit Area 3Psc	DMP, ASO coverage, VMS	Atlantic Halibut limit 10% to maximum of 200 lbs	Depth restriction, bycatch limits	Atlantic Cod gillnet, longline; Atlantic Halibut longline
Commercial <65' fleet	Water depths >75 fathoms.	Daily hails, DMP, ASO coverage, VMS	Atlantic Halibut limit 10% to maximum of 200 lbs, Cod 4% limit	Depth restriction, bycatch limits	Atlantic Cod gillnet, longline; Atlantic Halibut longline
Commercial Fixed Gear 65'-100' vessels	-	Daily hails, DMP, ASO coverage, VMS	Cod 4% limit	Bycatch limits	Atlantic Cod gillnet, longline; Atlantic Halibut longline; Redfish gillnet
Commercial Mobile Gear 65'-100' vessels	-	-	-	-	Redfish trawl, Witch Flounder trawl

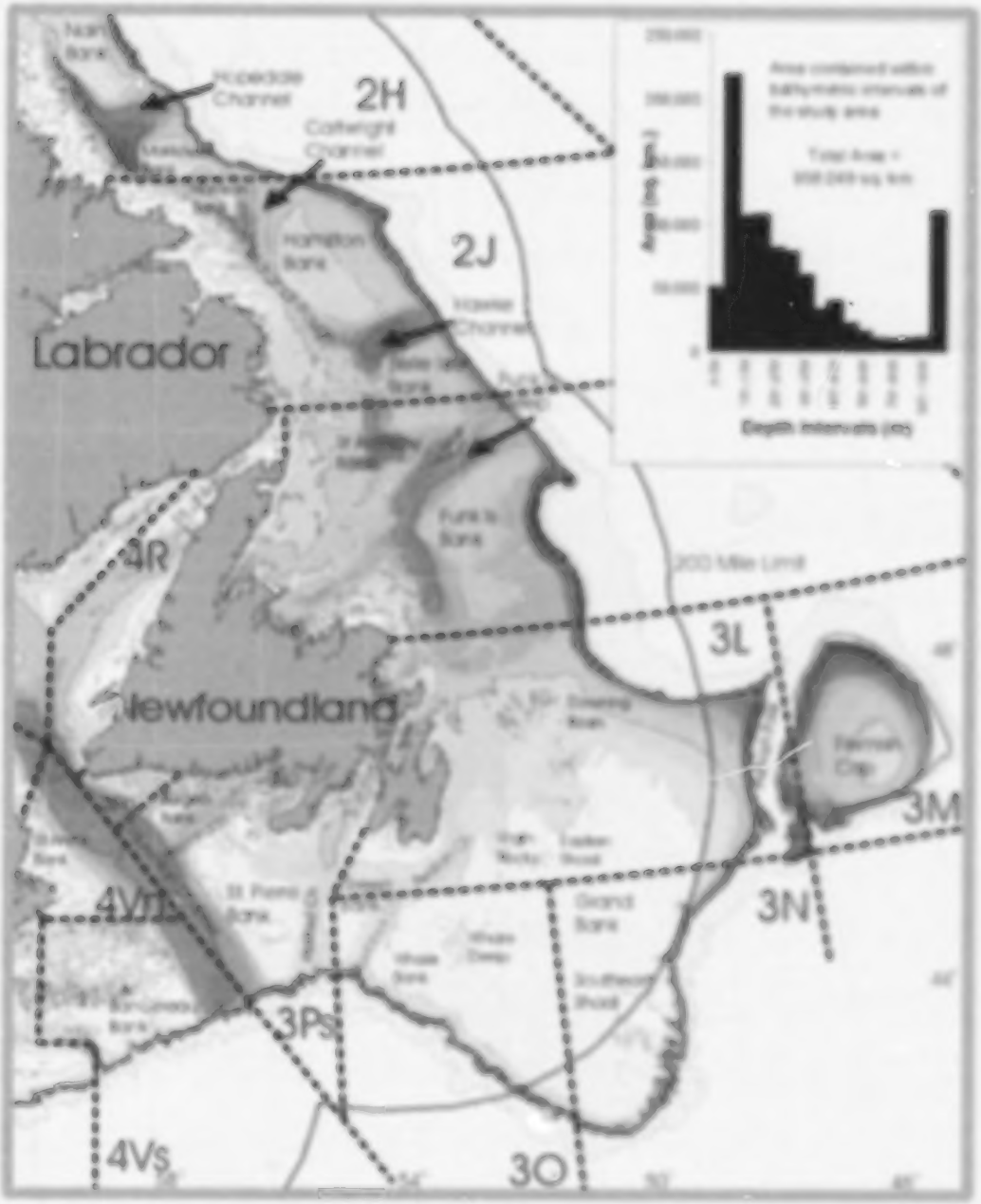


Figure 1. Map of the continental shelf off Eastern Canada and geographic features mentioned in the text. Depth range: < 100 m (light grey) to > 1000 m (dark grey). Canada's Exclusive Economic Zone is delineated by thin black dotted lines, and NAFO Divisions by thick black dashed lines.

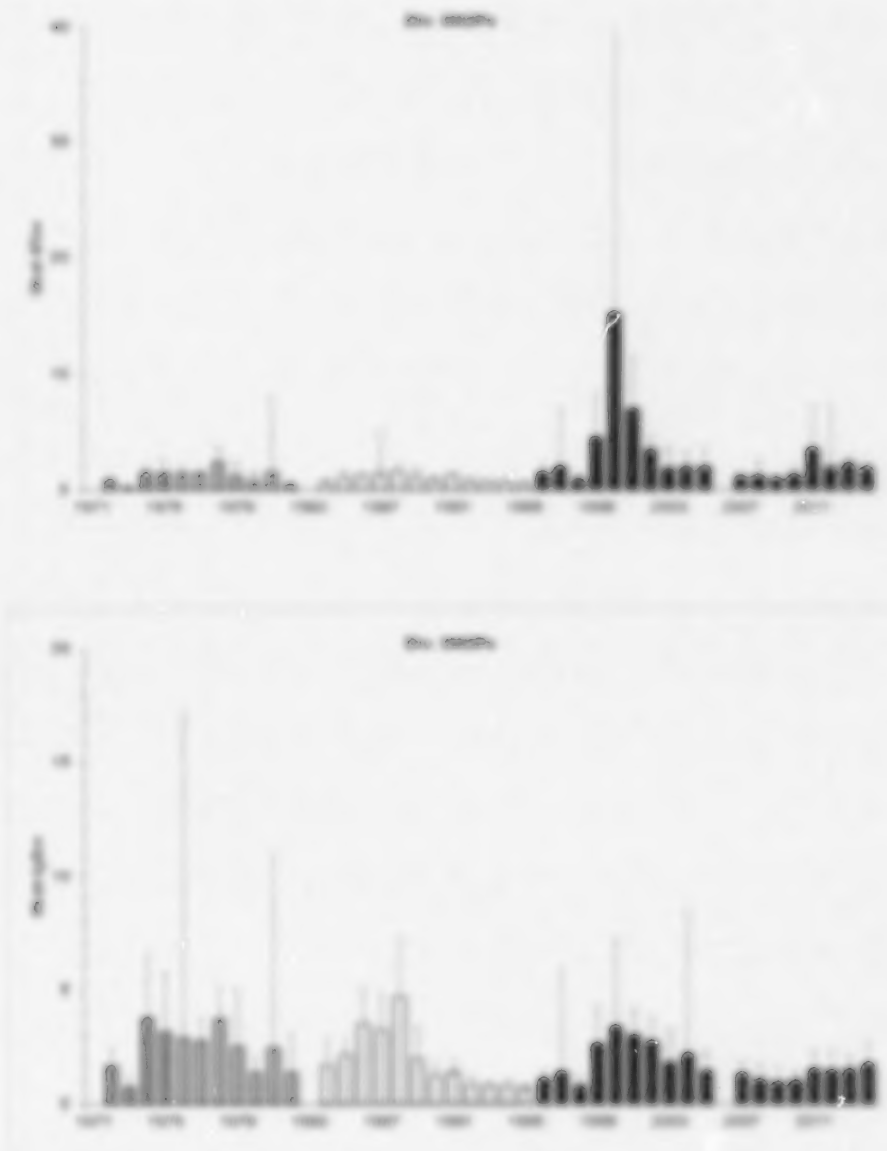


Figure 2. Mean numbers (upper panel) and mean weights (lower panel) per tow (+95 % CI) of White Hake from Canadian spring research surveys in Div. 3NO and Subdiv. 3Ps, 1972-2014. Survey trawl gear changed from Yankee (grey bars) to Engel (white bars) in 1983, and to Campelen (black bars) in 1995. Div. 3LNO were not surveyed in 1983, and the deeper (>183 m) portion of Div. 3NO, as well as Subdiv. 3Ps, were not surveyed in 2008 due to mechanical difficulties on Canadian research vessels.

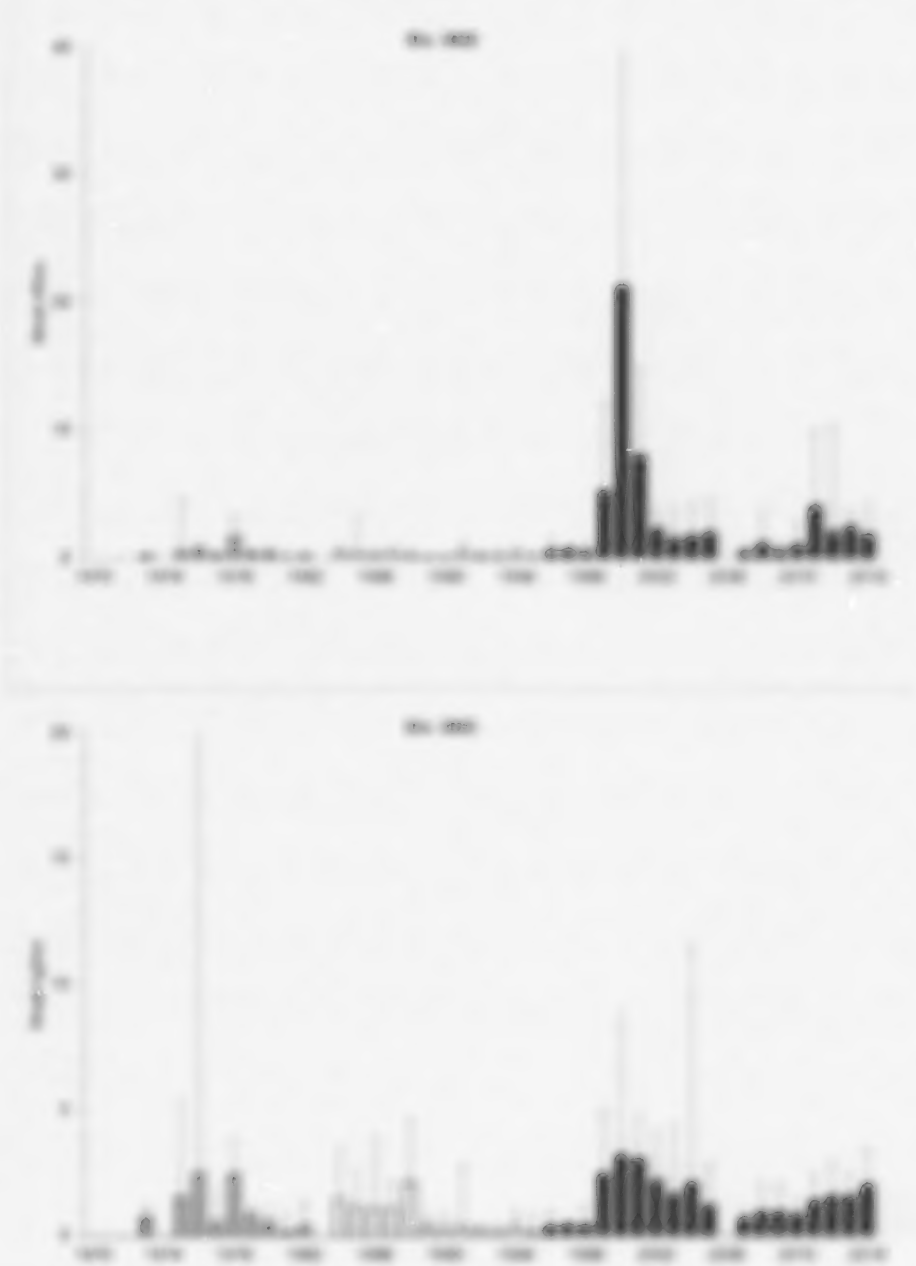


Figure 3. Mean numbers (upper panel) and mean weights (lower panel) per tow (+95 % CI) of White Hake from Canadian spring research surveys in Div. 3NO, 1973-2014. Survey trawl gear changed from Yankee (grey bars) to Engel (white bars) in 1983, and to Campelen (black bars) in 1995. Div. 3NO were not surveyed in 1983, and the deeper (>183 m) portion of Div. 3NO was not surveyed in 2006 due to mechanical difficulties on Canadian research vessels.

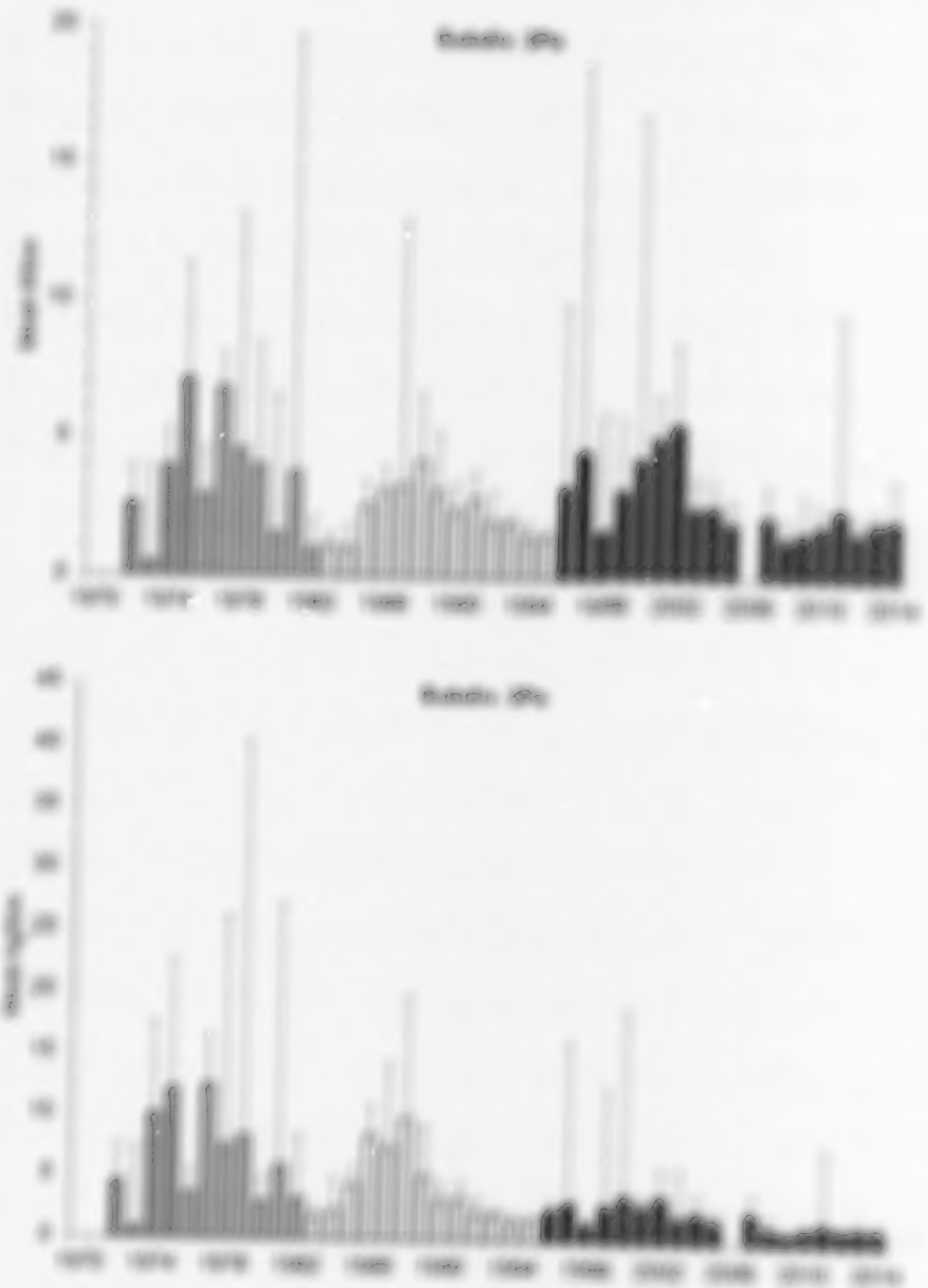


Figure 4. Mean numbers (upper panel) and mean weights (lower panel) per tow (+90 % CI) of White Hake from Canadian spring research surveys in Subdiv. 3Pn, 1970-2014. Survey timing and gear changes from Yankee (grey bars) to Engel (white bars) in 1982, and to Campelen (black bars) in 1995. Subdiv. 3Ps was surveyed in 2005, due to mechanical difficulties on Canadian research vessels.

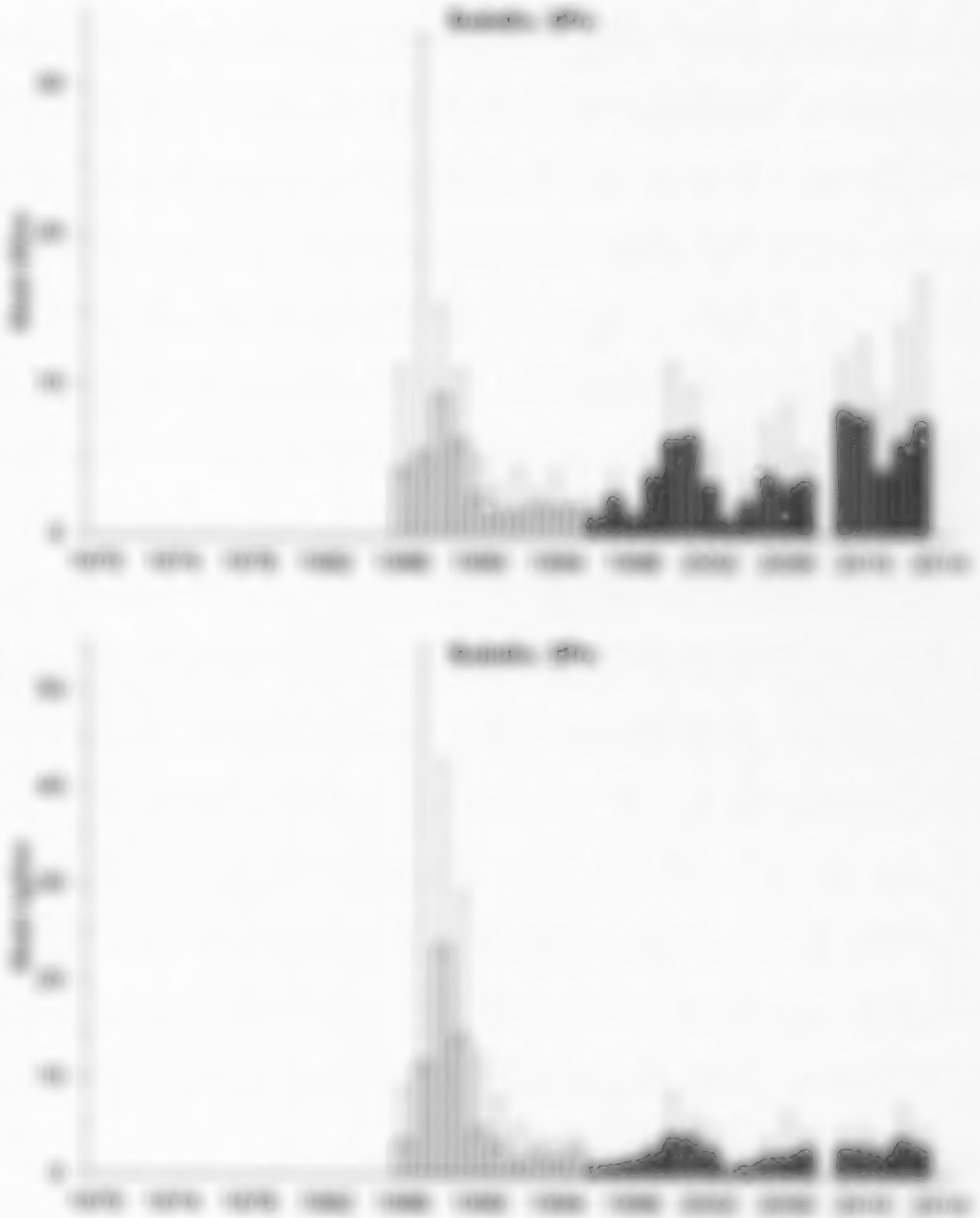


Figure 2. Mean numbers (upper panel) and mean weights (lower panel) per tow (+95 % CI) of Atlantic mackerel caught in autumn research surveys in Ireland, 1972–2008 (IE) and during the International Young Gadoid Survey in the Celtic Sea (IGFS), 1991–2008. Surveys were carried out using comparable gear.

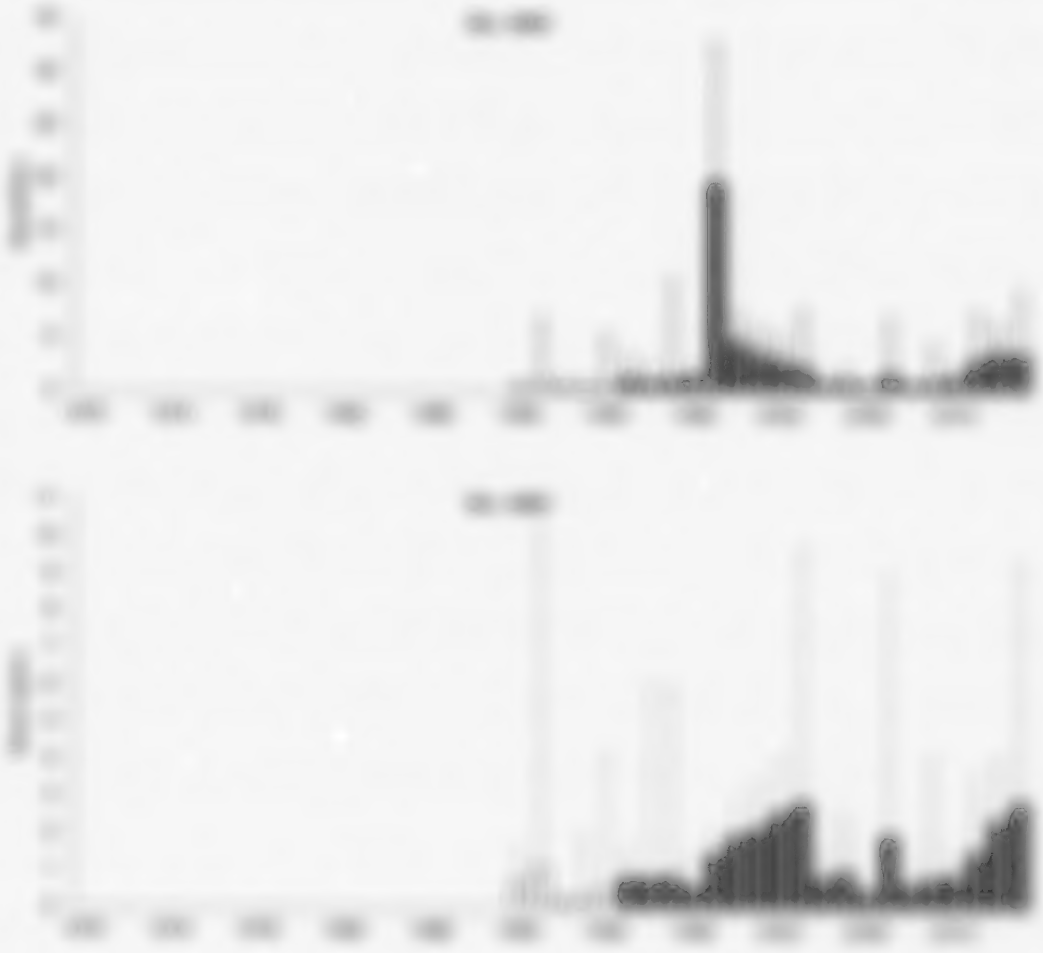


Figure 8. Geographic distribution of DFO research survey catches of White Hake in NAFO Subareas 2, 3, 4, and 5, 1977-90. Div. 3LNO were not surveyed in 1983, due to mechanical difficulties on Canadian research vessels.

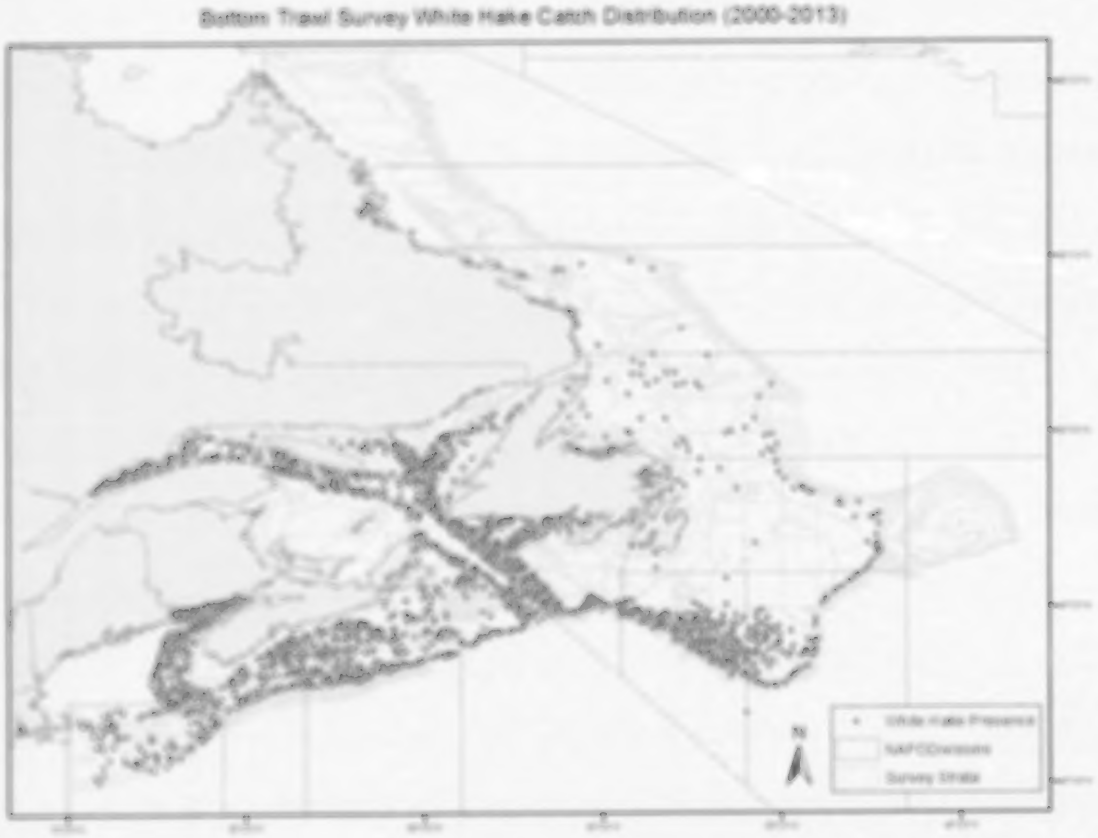


Figure 9. Geographic distribution of DFO research survey catches of White Hake in NAFO Subareas 2, 3, 4, and 5, 2000-13. The deeper (>183 m) portion of Div. 3NO, as well as Subdiv. 3Ps, were not surveyed in 2006.

Figure 10. Cumulative frequency distributions (CFDs) of White Hake temperature associations in Div. 3O from DFO-NL spring Campelen surveys, 2002-14. Dotted line represents the catch and design-weighted distribution. The 2006 graph is not shown due to an incomplete survey.

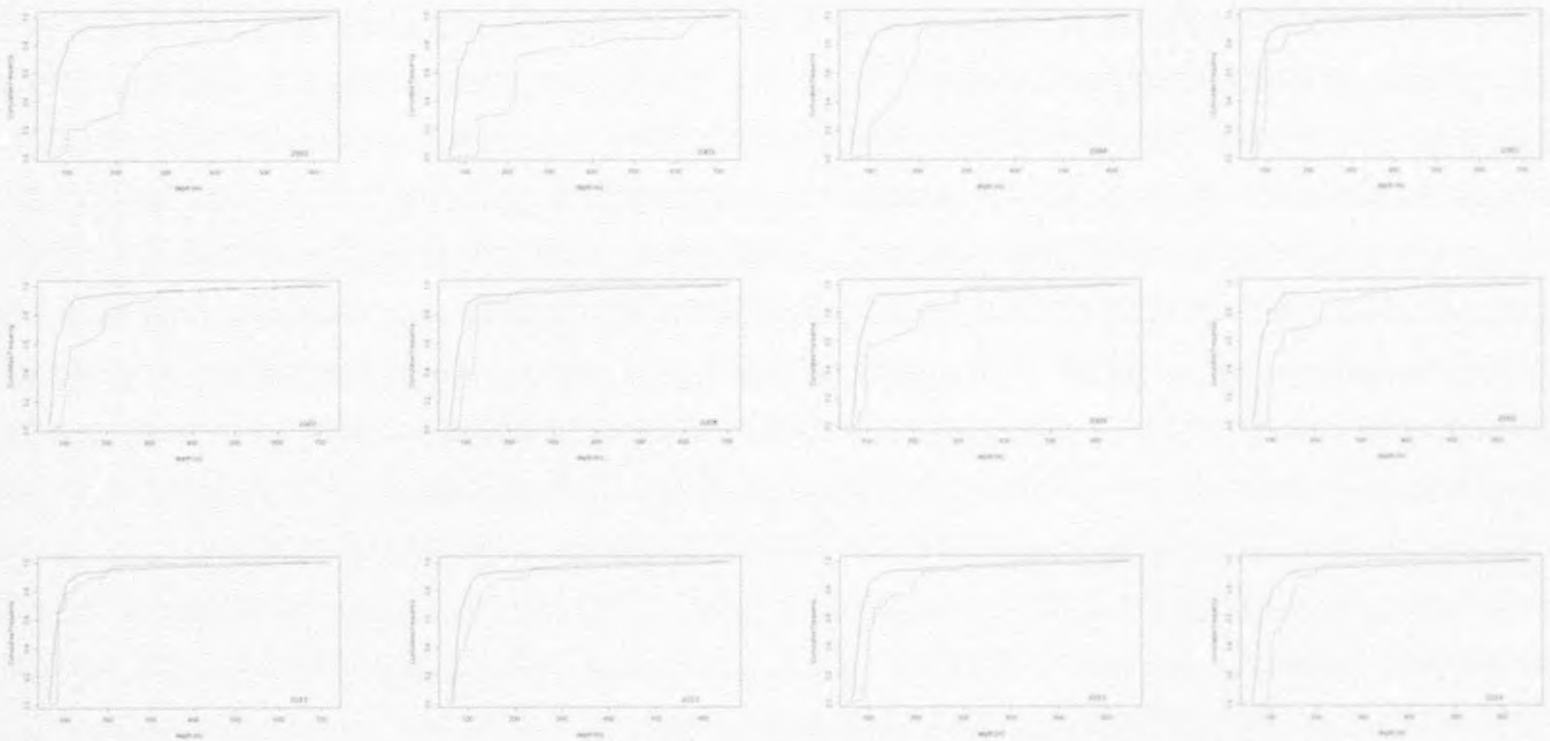


Figure 11. CFDs of White Hake depth associations in Div. 3O from DFO-NL spring Campelen surveys, 2002-14. Dotted line represents the catch and design-weighted distribution.

Figure 12. CFDs of White Hake temperature associations in Subdiv. 3Ps from DFO-NL spring Campelen surveys, 2002-14. Dotted line represents the catch and design-weighted distribution. The 2006 graph is not shown due to an incomplete survey.

Figure 13. CPEs of Whale Hake depth associations in Subdiv. 3Ps from DFO-Alf, using Canyonter surveys, 2002-16. Dotted line represents the catch and design-weighted distribution.

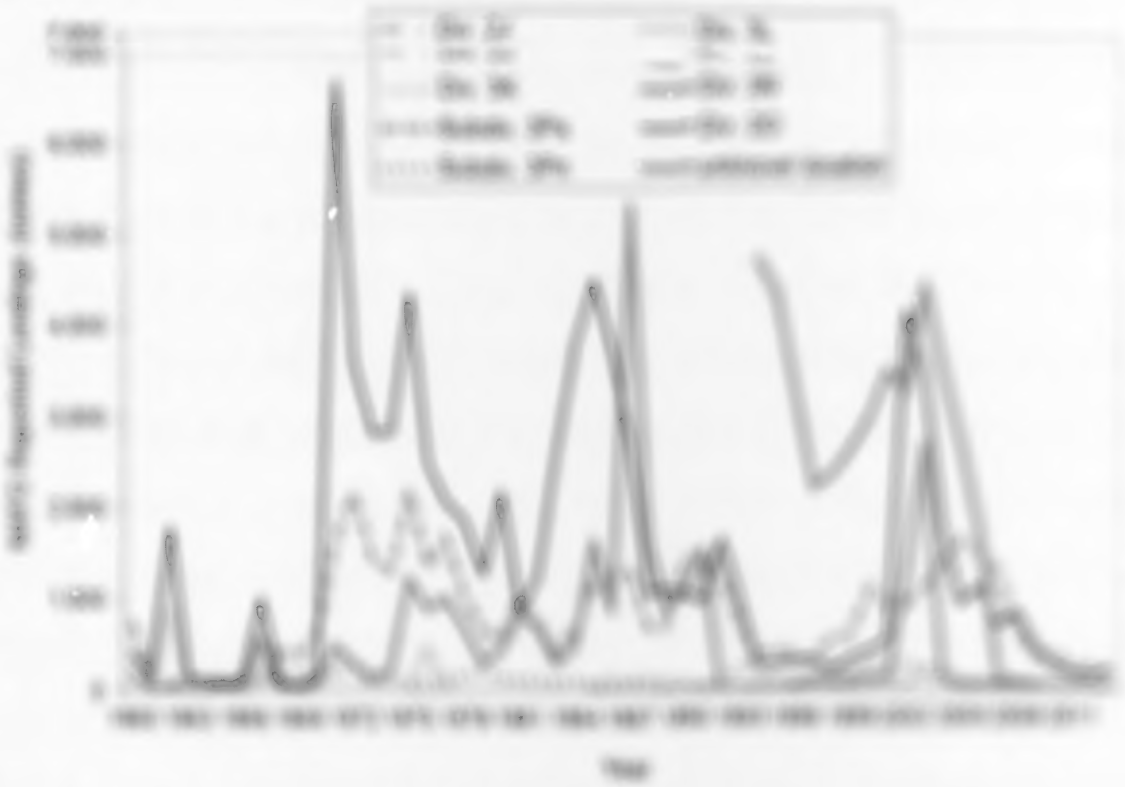
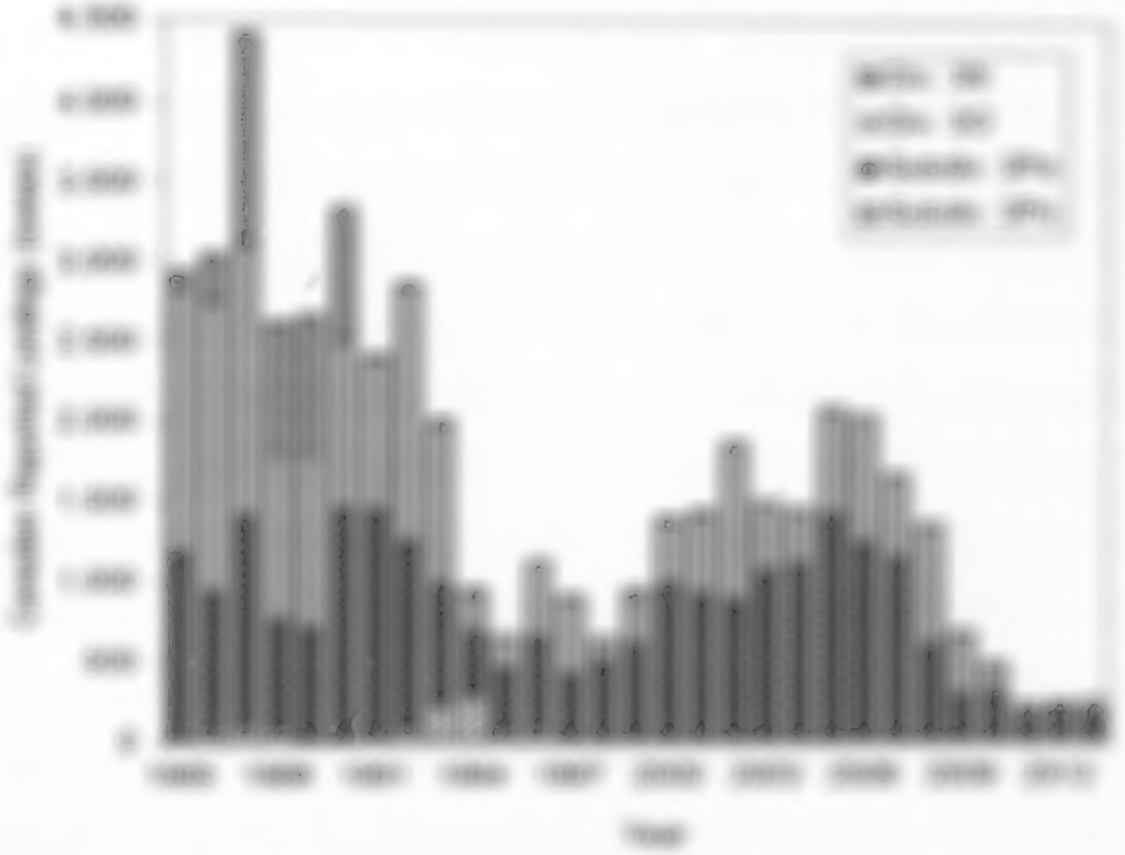
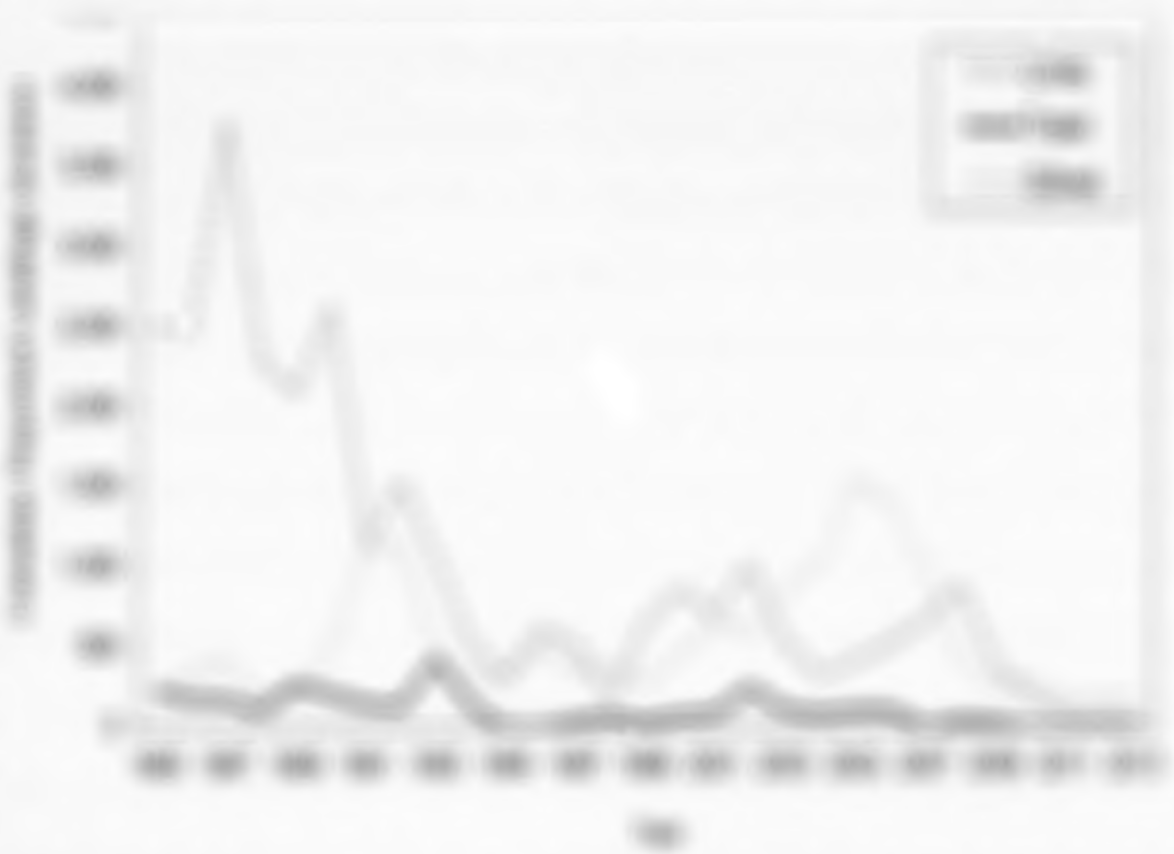


Figure 14: NMFS-reported landings (tonnes) of White Hake by statistical rectangles in Div. 3Ps (1954-2007; 1994-2001 in 3Ps4VsW; 2007 in 4Vs).


Year

Year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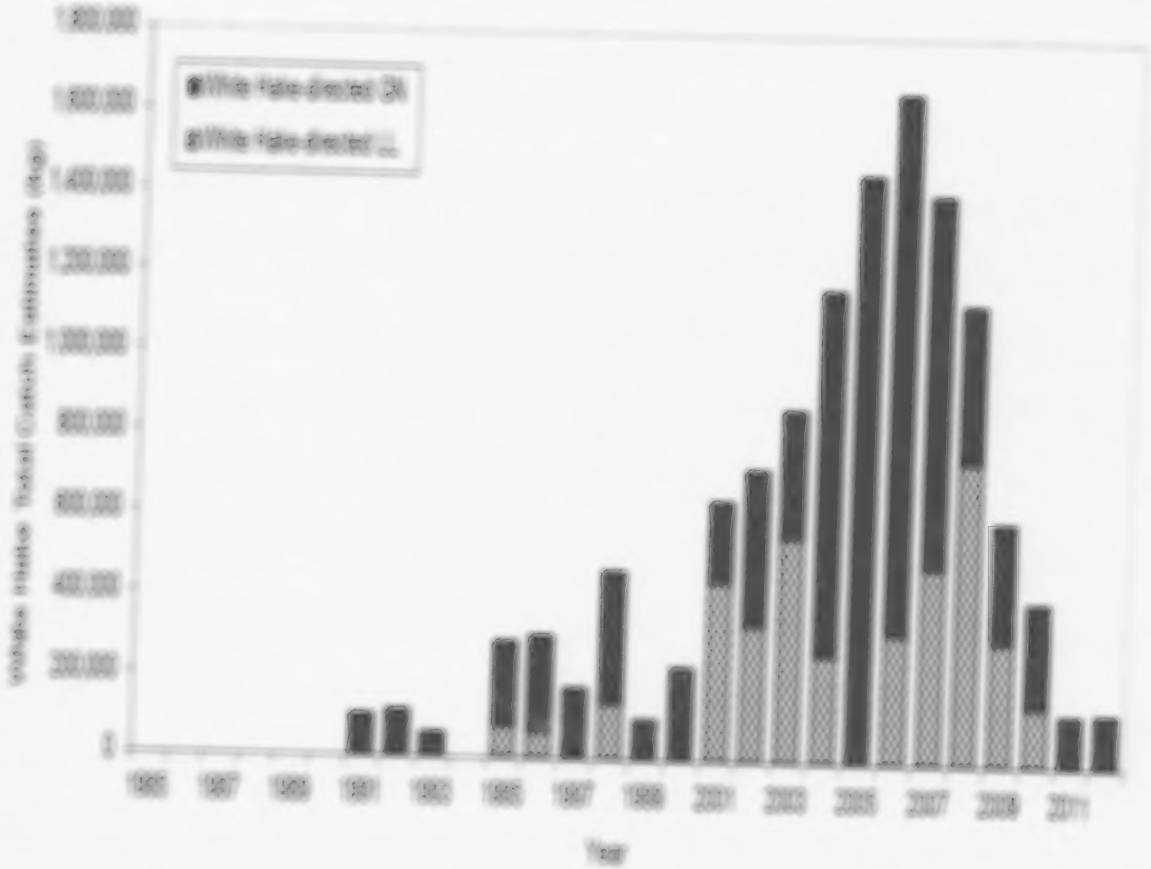


Figure 10. Estimated annual total catch (kgs) of White Hake in directed gillnet (GN) and longline (LL) fisheries in Canada's EEZ of Div. 3NOPf, 1985-2012. Data are from Canadian At-Sea Fisheries Observers and DFO-NL ZIFF in comparable years.

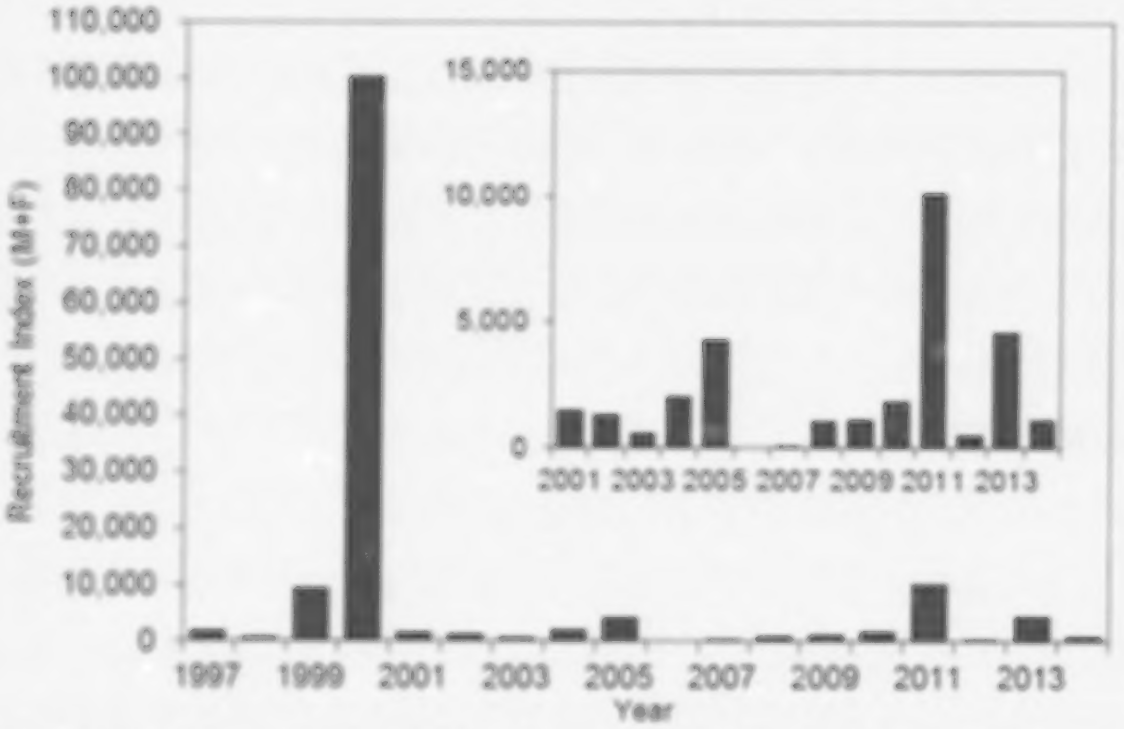


Figure 19. White Hake recruitment index for Age 1 males and females (combined) from DFO-NL Campelen spring surveys in Div. 3NOPs, 1997-2014. Inset plot depicts 2001-14 on a smaller scale. Estimates from 2006 are not shown, since survey coverage in that year was incomplete.

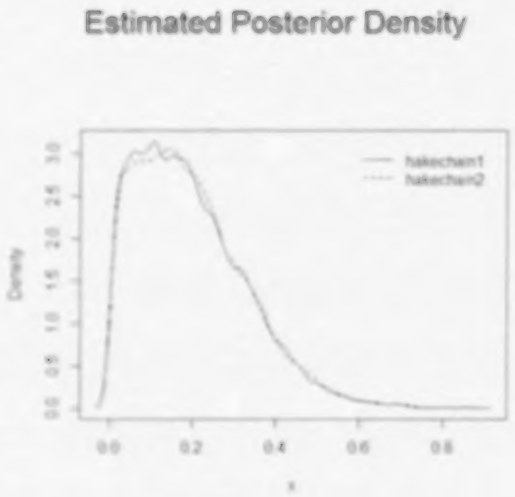


Figure 20a. Kernel density estimates of the posterior distribution of r for both chains.

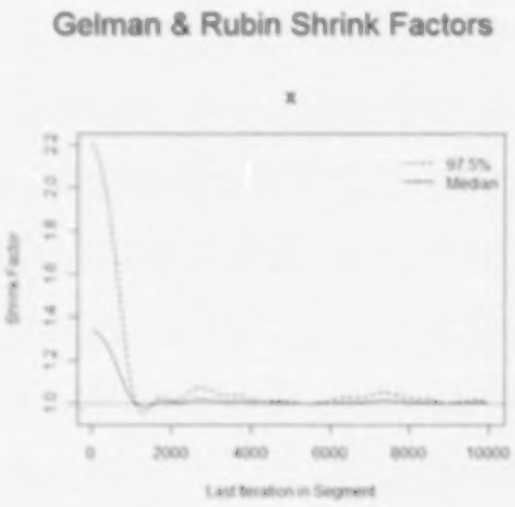


Figure 20b. Gelman and Rubin shrink factors for r. Gelman & Rubin shrink factors examining the reduction in bias in estimation. The shrink factor approaches 1 when the pooled within-chain variance dominates the between-chain variance. At that point, all chains have escaped the influence of their starting points.

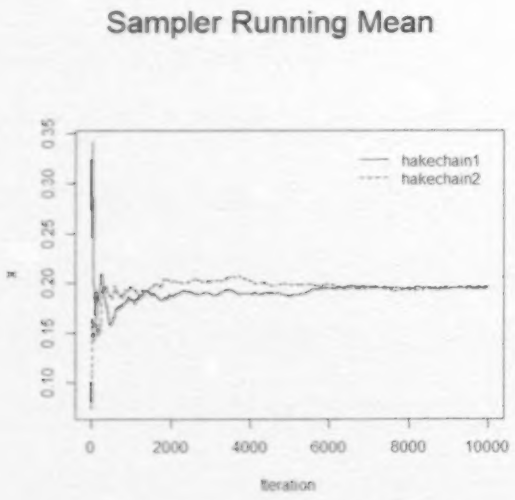


Figure 20c. Sampler running mean for r.

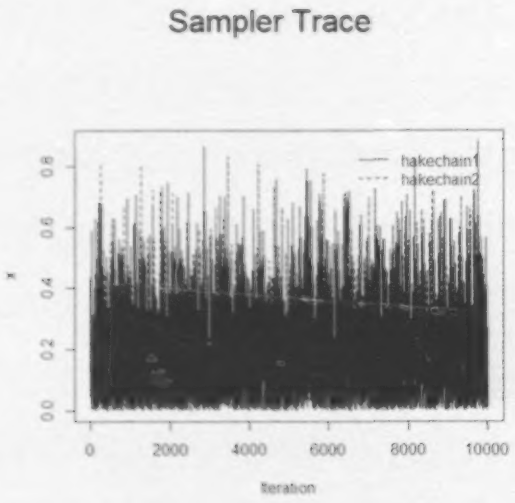


Figure 20d. A time series trace of the sampled points for r in both chains.

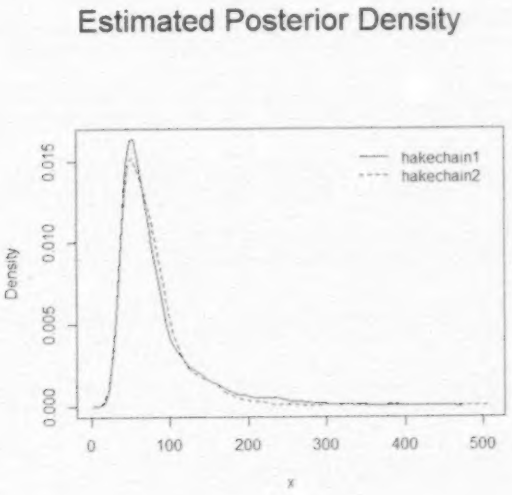


Figure 21a.Kernel density estimates of the posterior distribution of K for both chains.

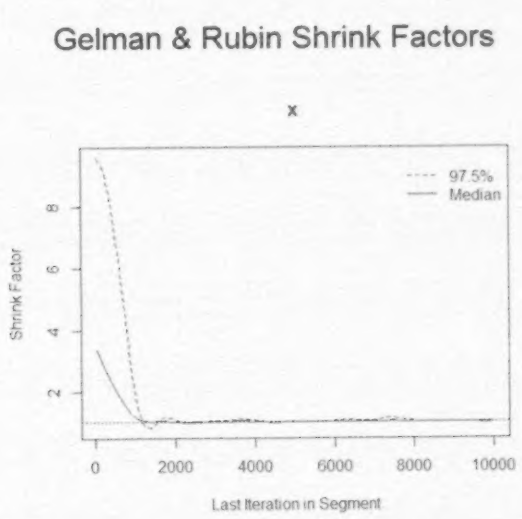


Figure 21b.Gelman and Rubin shrink factors for K. Gelman & Rubin shrink factors examining the reduction in bias in estimation. The shrink factor approaches 1 when the pooled within-chain variance dominates the between-chain variance. At that point, all chains have escaped the influence of their starting points.

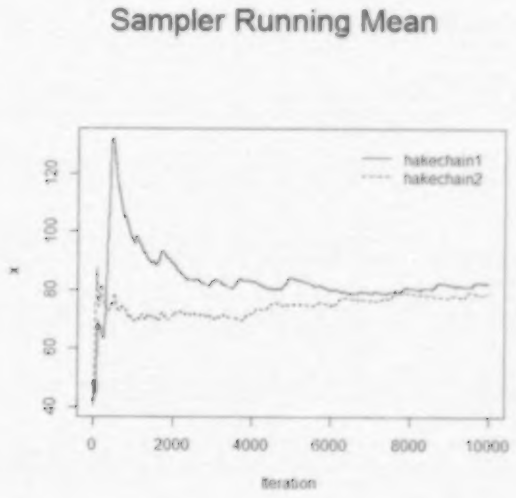


Figure 21c. Sampler running mean for K.

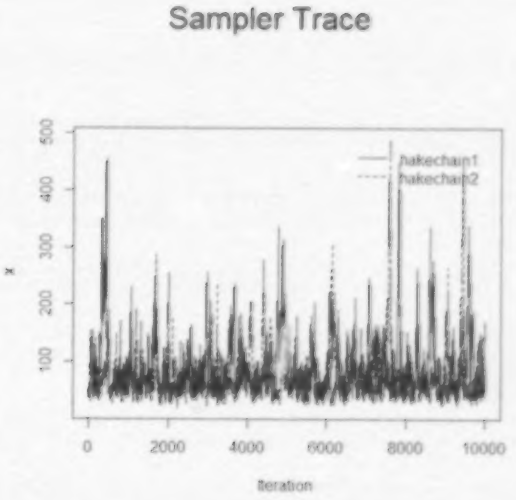


Figure 21d. A time series trace of the sampled points for K in both chains.

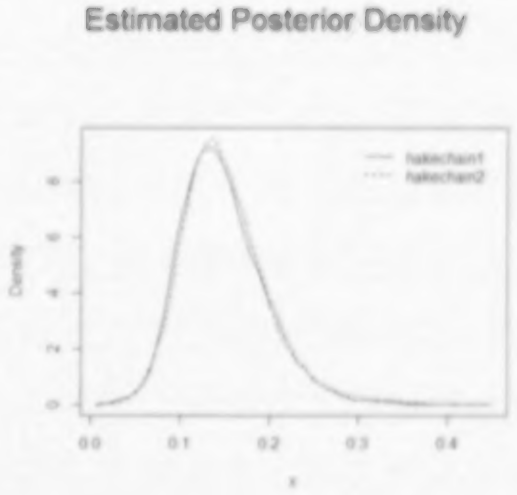


Figure 22a. Kernel density estimates of the posterior distribution of sigma (process error) for both chains.

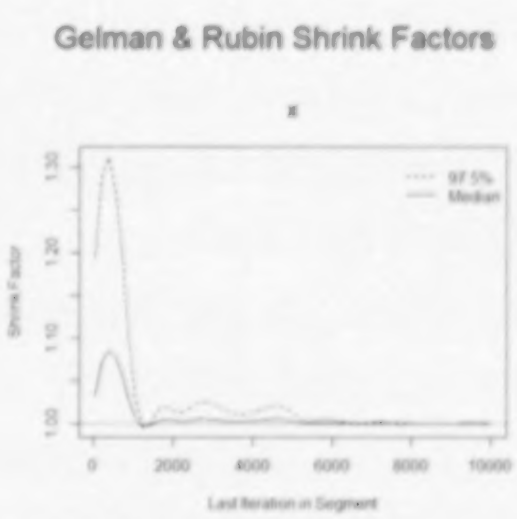


Figure 22b. Gelman and Rubin shrink factors for sigma. Gelman & Rubin shrink factors examining the reduction in bias in estimation. The shrink factor approaches 1 when the pooled within-chain variance dominates the between-chain variance. At that point, all chains have escaped the influence of their starting points.

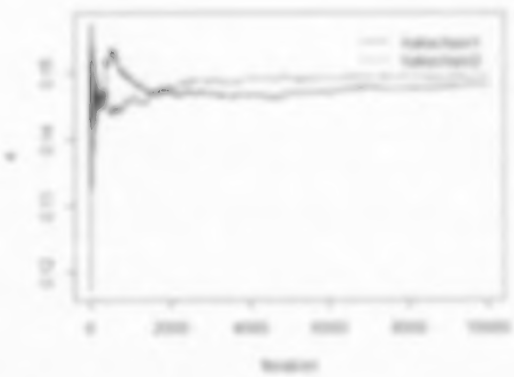


Figure 22c. Sampler running mean for sigma.

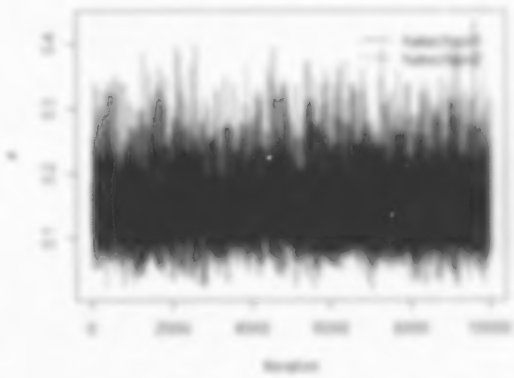


Figure 22d. A time series trace of the sampled points for sigma in both chains.

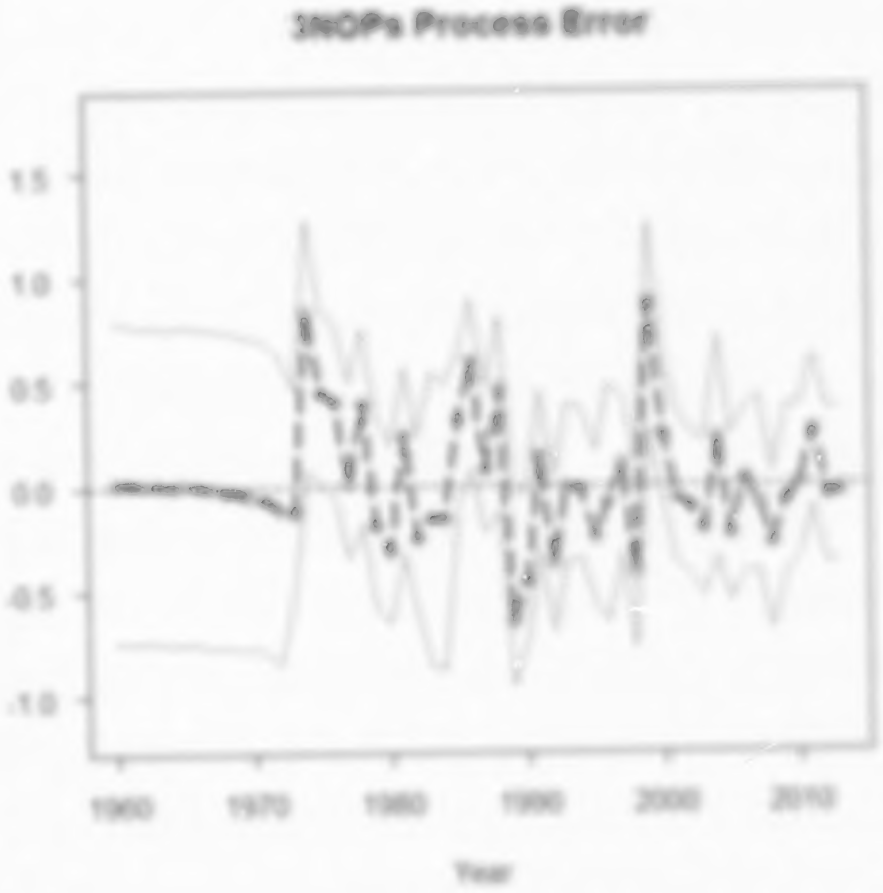


Figure 23. Process error (sigma) from the surplus production model for White Hake in Div. 3NOPs.

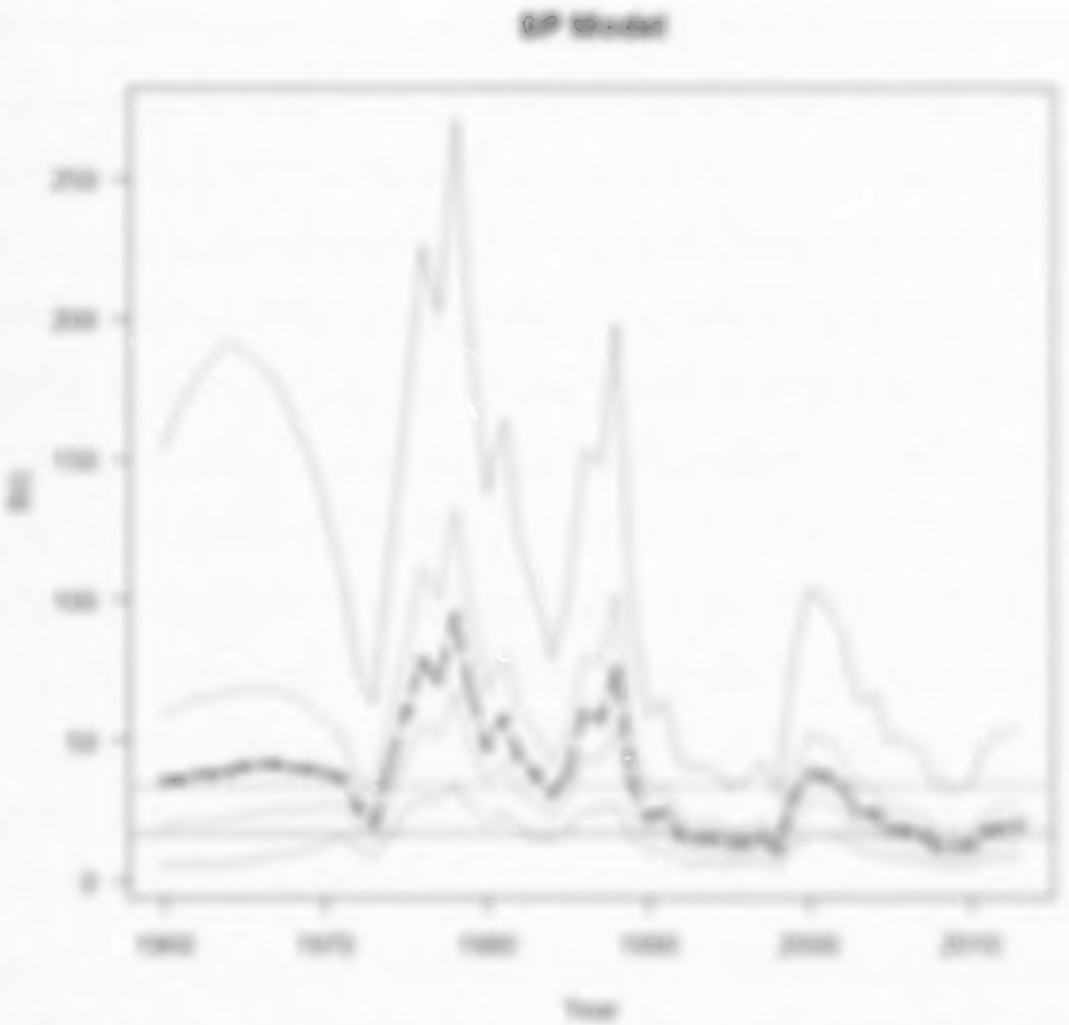


Figure 24. Schaefer surplus production model of median biomass (kt) in 1960-2013 (bold dashed line) for White Hake in Div. 3NOPs. Black dotted lines represent 50 % and 95 % credible intervals; red solid line B/B_{MSY}; and red stippled line B/B_{MSY}.

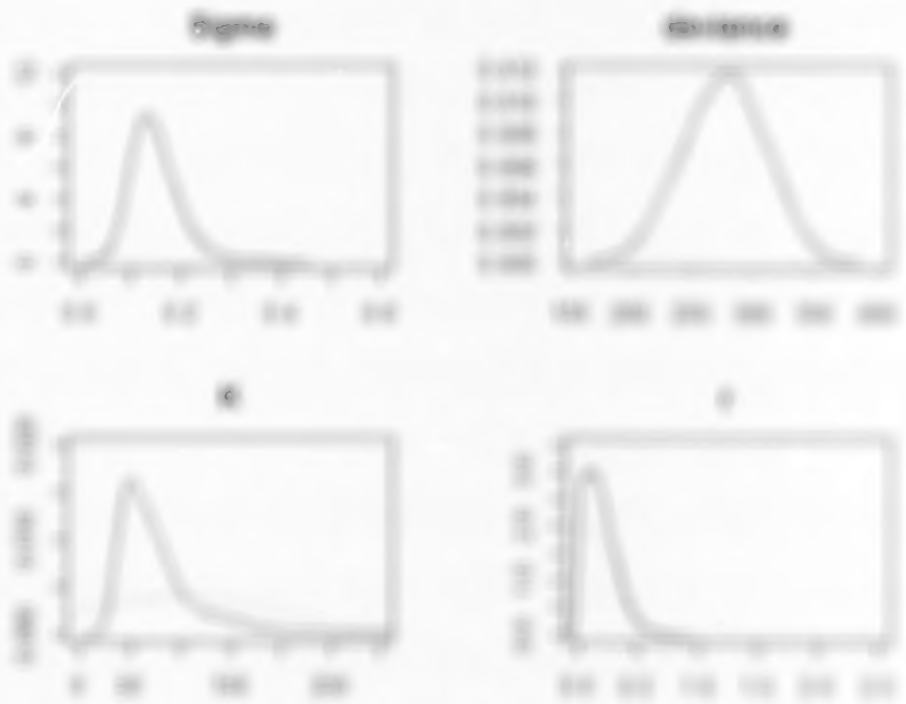


Figure 26. Posterior distributions for deviance, carrying capacity (K), intrinsic rate of population growth (r), and process error precision (sigma) for White Hake in Div. 3NOPS. Prior distributions are shown as r, k, and sigma (red dotted lines).

Figure 27. Posterior (black solid line) and prior (red dotted lines) distributions of catchability (q) for the (L) and Optional time series for White Hake in Div. 3NOPS.

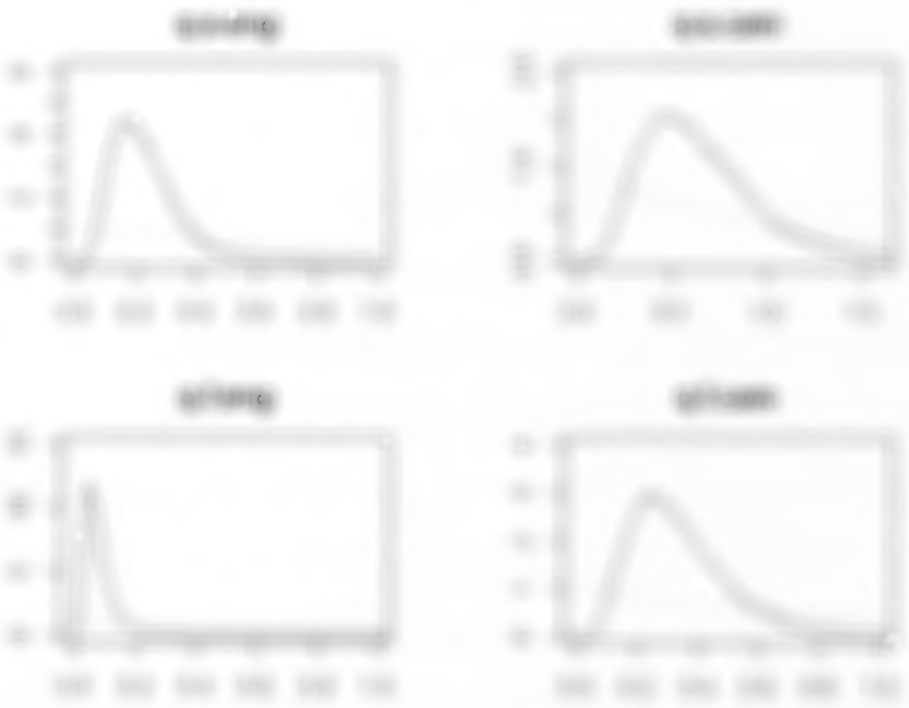


Figure 27 - Posterior (black solid line) and prior (red dashed line) distributions of permeability (g/cm/day) for the Bright and Hampshire clayey and Hall sandy silt. White noise in (b). (BIGM).

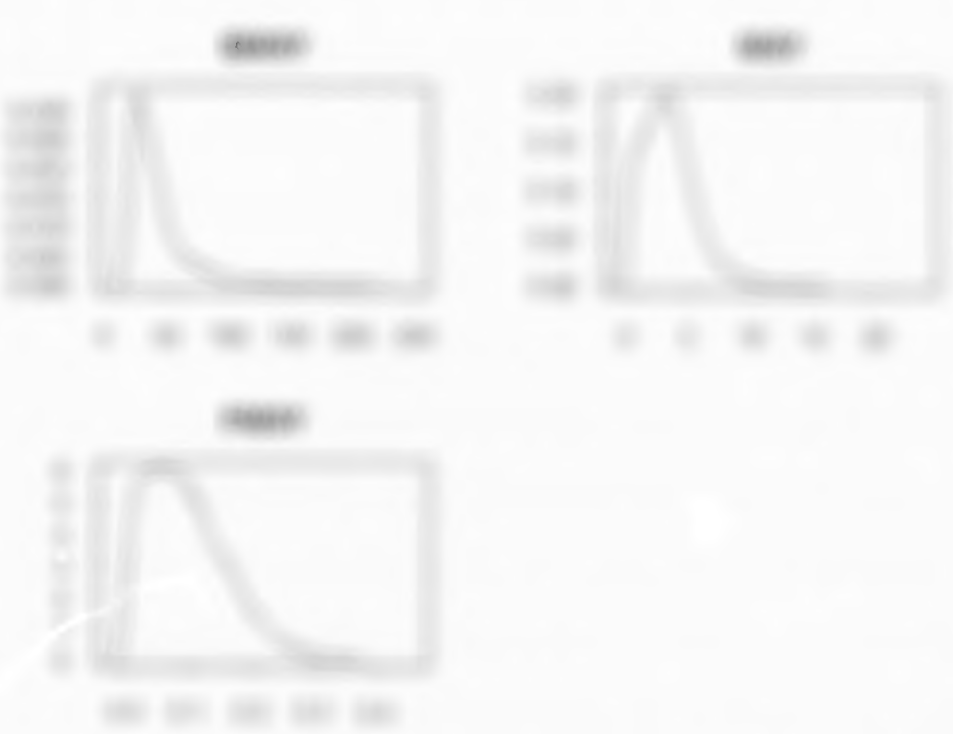
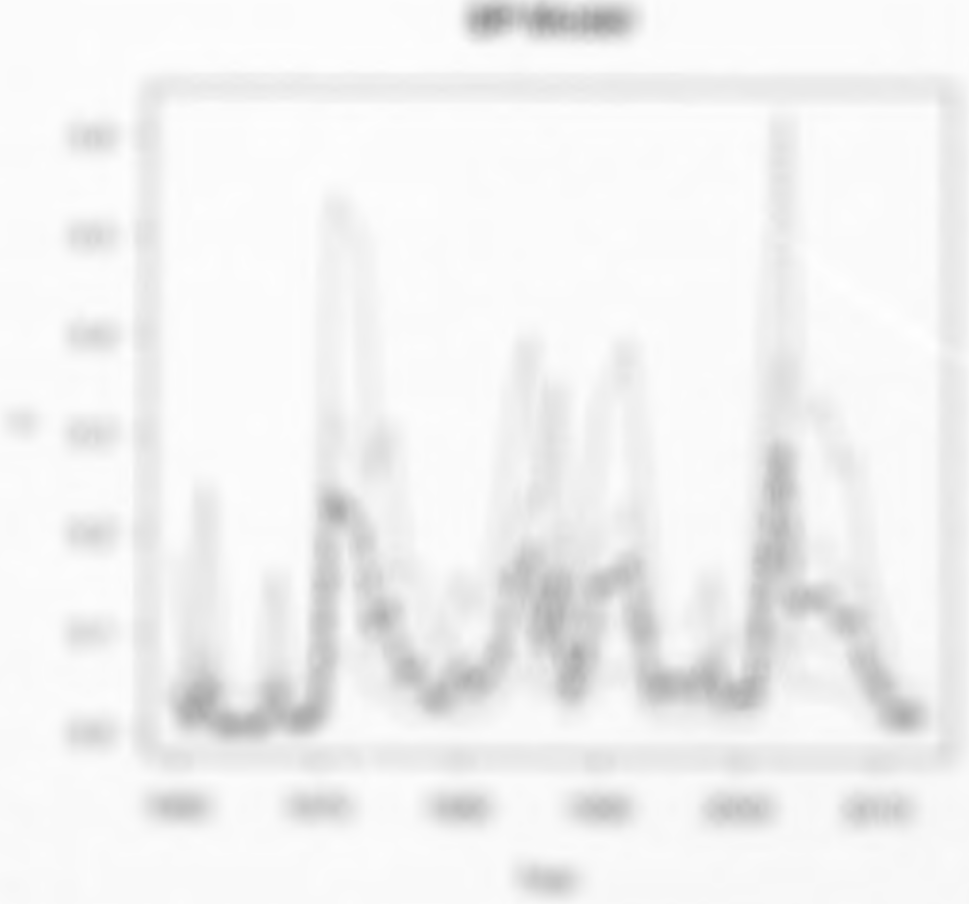


Figure 3B: Potential distributions for Ca_{1-x} (BCT) and Fr_{1-x} on (Mild) steps in (Ca). (BCT)


Year

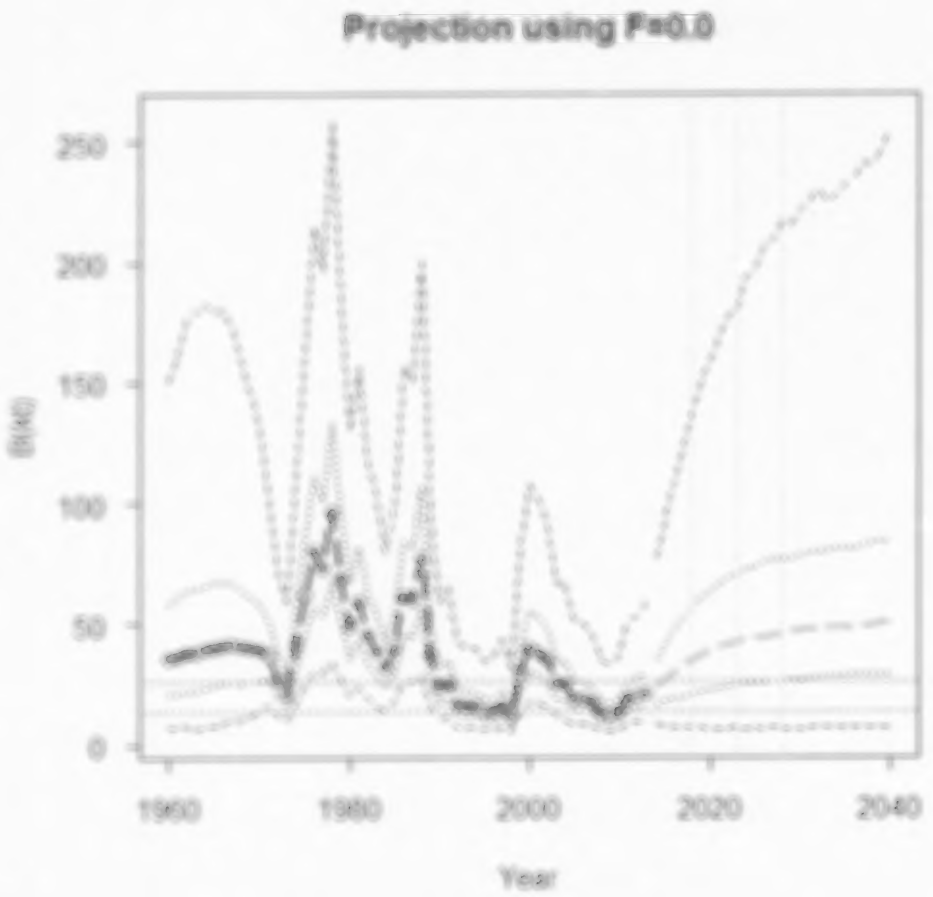


Figure 30. Bayesian surplus production estimates of historical (1960-2012) and predicted biomass (kt) for the next 27 years at F=0.0. B_{msy} at $0.4*B_{MSY}$ and $0.8*B_{MSY}$ are indicated by the horizontal blue dotted lines. Time horizons of 5, 10, and 15 years forward are indicated by vertical green dotted lines. The 25 % and 75 % credible limits are enclosed in the black dotted lines. Black dashed lines represent 2.5 % and 97.5 % credible limits, and the red dashed line follows the median biomass for projected years.

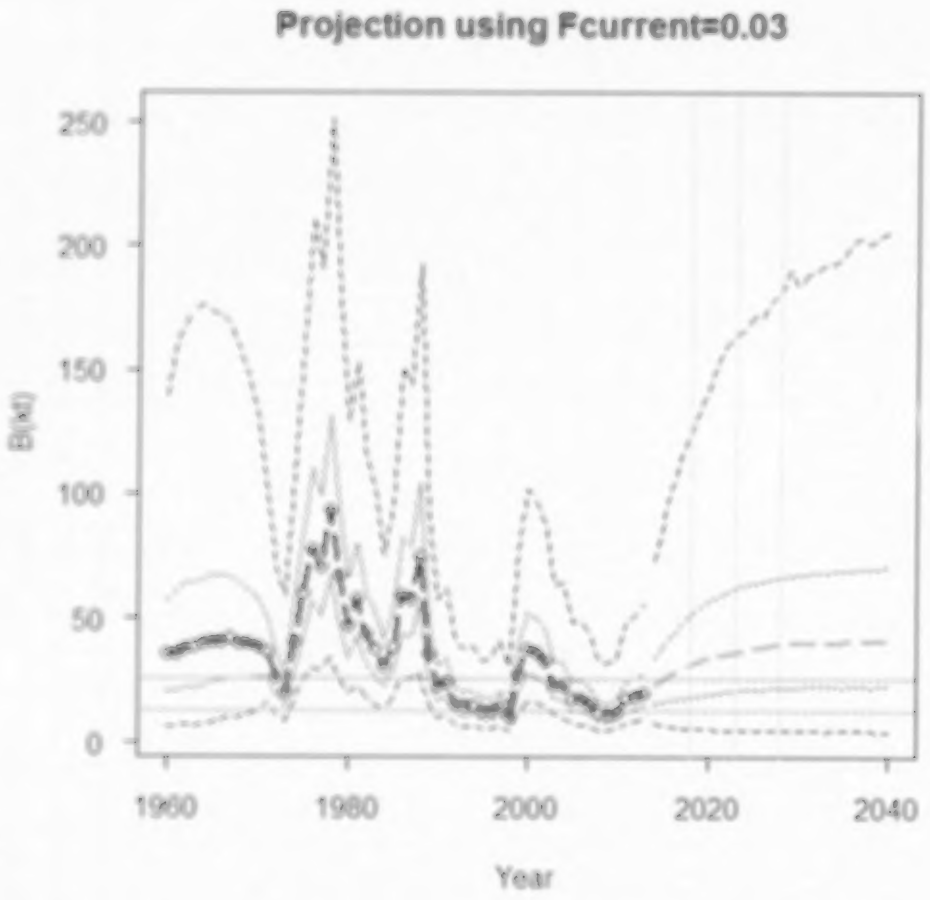


*Figure 31. Bayesian surplus-production estimates of historical (1960-2013) and predicted biomass (kt) for the next 27 years at $F_{current}$=0.03. B_{MSY} at 0.4*B_{MSY} and 0.8*B_{MSY} are indicated by the horizontal blue dotted lines. Time horizons of 5, 10, and 15 years forward are indicated by vertical green dotted lines. The 25 % and 75% credible limits are enclosed in the black dotted lines. Black dashed lines represent 2.5 % and 97.5% credible limits, and the red dashed line follows the median biomass for projected years.*

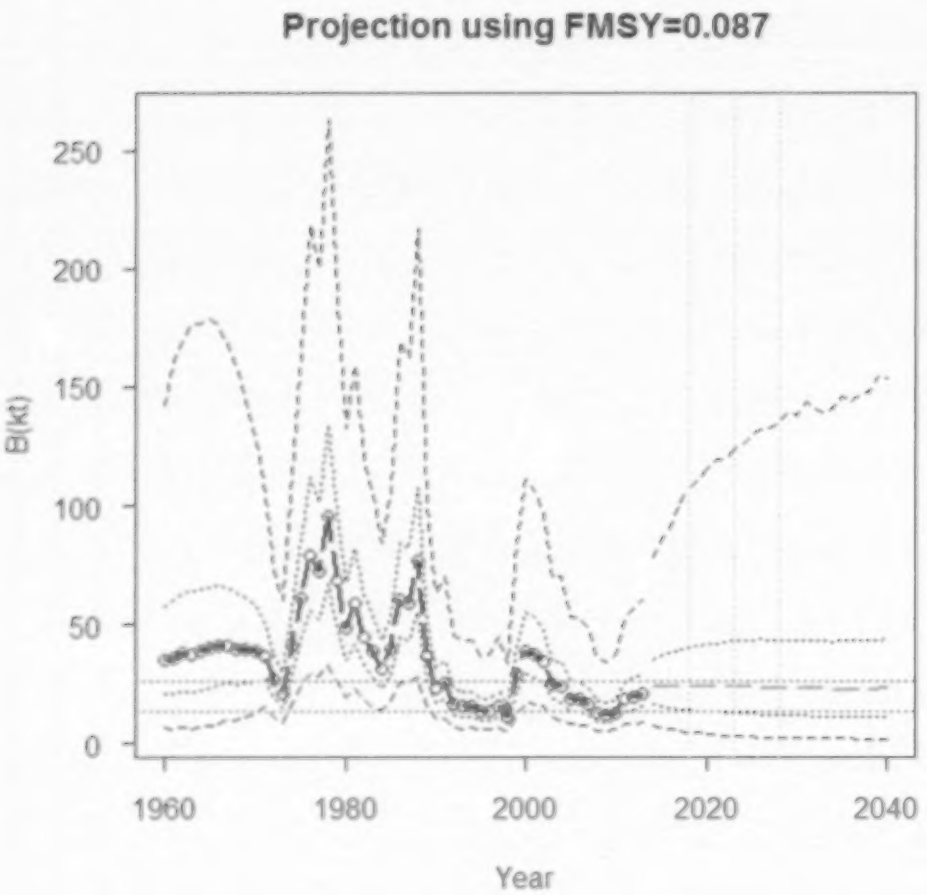


*Figure 32. Bayesian surplus-production estimates of historical (1960-2013) and predicted biomass (kt) for the next 27 years at F_{MSY}=0.087. B_{lim} at 0.4*B_{MSY} and 0.8*B_{MSY} are indicated by the horizontal blue dotted lines. Time horizons of 5, 10, and 15 years forward are indicated by vertical green dotted lines. The 25 % and 75% credible limits are enclosed in the black dotted lines. Black dashed lines represent 2.5 % and 97.5 % credible limits, and the red dashed line follows the median biomass for projected years.*

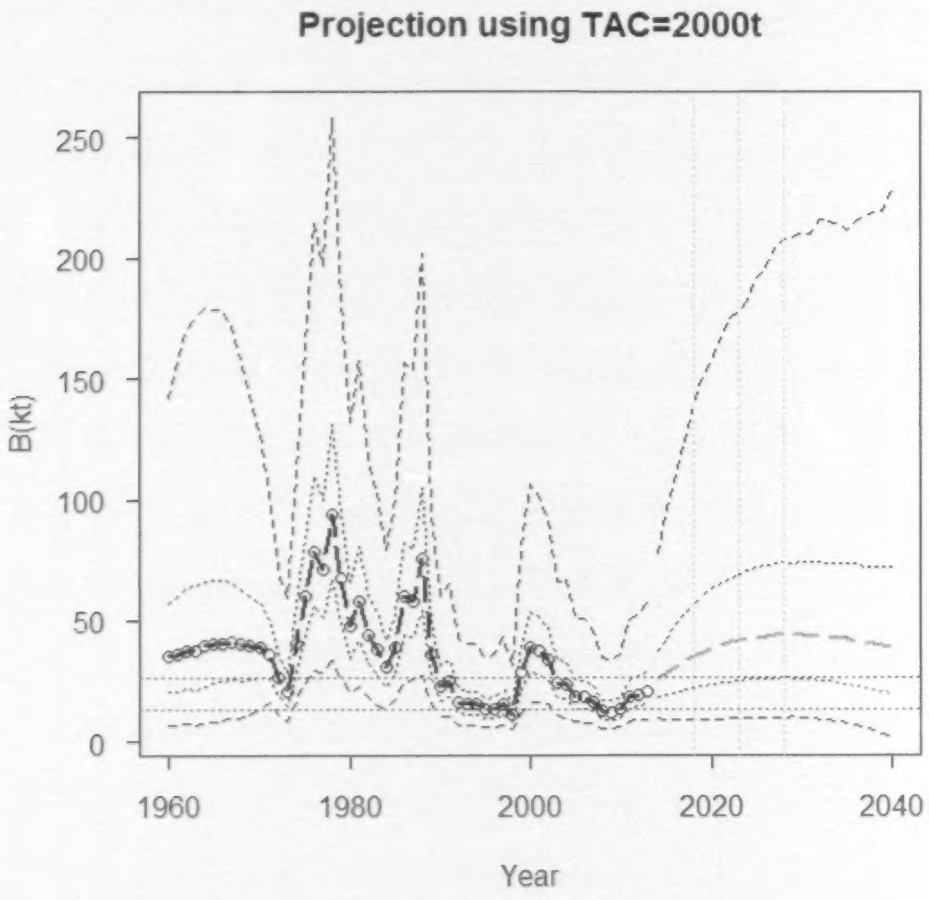


*Figure 33. Bayesian surplus-production estimates of historical (1960-2013) and predicted biomass (kt) for the next 42 years at F_{TAC}=2000t/yr. B_{lim} at 0.4*B_{MSY} and 0.8*B_{MSY} are indicated by the horizontal blue dotted lines. Time horizons of 5, 10, and 15 years forward are indicated by vertical green dotted lines. The 25 % and 75 % credible limits are enclosed in the black dotted lines. Black dashed lines represent 2.5% and 97.5 % credible limits, and the red dashed line follows the median biomass for projected years.*